NOV 8 1988

631-A

I28.23:9187

RI 9187

REPORT OF INVESTIGATIONS/1988

# Foundation Response to High-Extraction Mining in Southern Illinois

By Larry R. Powell, Theodore L. Triplett, and Ronald E. Yarbrough

COMPLETED

BUREAU OF MINES

UNITED STATES DEPARTMENT OF THE INTERIOR

ORIGINAL

Report of Investigations 9187

# Foundation Response to High-Extraction Mining in Southern Illinois

By Larry R. Powell, Theodore L. Triplett,
and Ronald E. Yarbrough

UNITED STATES DEPARTMENT OF THE INTERIOR
Donald Paul Hodel, Secretary

BUREAU OF MINES
T S Ary, Director

Library of Congress Cataloging in Publication Data:

**Powell, Larry R.**

Foundation response to high-extraction mining in Southern Illinois.

(Report of investigations ; 9187)

Bibliography: p. 44-45.

Supt. of Docs. no.: I 28.23:9187.

1. Foundations. 2. Mine subsidences. 3. Earth movements and building. I. Triplett, Theodore, L. II. Yarbrough, Ronald E. III. Title. IV. Series: Report of investigations (United States. Bureau of Mines) ; 9187.

TN23.U43 [TA775] 622 s [624.1'51] 88-600125

CONTENTS


| | Page |
|---|---|
| Abstract | 1 |
| Introduction | 2 |
| Acknowledgments | 3 |
| Site description | 3 |
| Mining practices | 4 |
| Foundation design | 8 |
| Monitoring plan | 9 |
| Ground surface movements | 11 |
| Vertical displacements | 11 |
| Horizontal displacements | 15 |
| Foundation response | 17 |
| Vertical displacements | 17 |
| Horizontal displacements | 17 |
| Tilt | 19 |
| Foundation damage | 26 |
| Discussion of results | 28 |
| Summary and conclusions | 40 |
| References | 44 |
| Appendix A.--Vertical displacements | 46 |
| Appendix B.--Horizontal movements and directions | 52 |
| Appendix C.--Tilt directions and magnitudes | 53 |


ILLUSTRATIONS


| | | |
|---|---|---|
| 1. | Site location | 4 |
| 2. | East-west geologic cross section | 5 |
| 3. | General mine map | 6 |
| 4. | Mining schedule highlighting selected face positions | 7 |
| 5. | General difference between typical and modified foundations | 8 |
| 6. | Construction and bin location details for foundation B | 9 |
| 7. | Site survey network showing position of subsidence monuments on north-south and east-west base lines | 10 |
| 8. | Location of survey points and tiltplates on foundations | 11 |
| 9. | Tiltmeter system showing ceramic tiltplate, sensor, and digital readout | 12 |
| 10. | Change in north-south subsidence profiles with time | 13 |
| 11. | Relative displacements between ground surface and foundations | 14 |
| 12. | Horizontal displacements measured at site | 16 |
| 13. | Horizontal displacements measured on east-west base line | 16 |
| 14. | Vertical displacements of foundations | 18 |
| 15. | Differential vertical displacement of foundations when they cracked | 19 |
| 16. | Horizontal displacement of foundations | 21 |
| 17. | Foundation distortion caused by differential horizontal movement | 22 |
| 18. | Magnitude and direction of foundation tilt before and after cracking | 23 |
| 19. | Tilt direction change for northeast and southwest corners of foundations | 24 |
| 20. | Change in tilt for typical foundation A | 25 |
| 21. | Change in tilt for modified foundation B | 25 |
| 22. | Tilt before and after western panel completed | 26 |
| 23. | Southeast corner of foundation A | 27 |
| 24. | Foundation crack locations and dates first observed | 28 |
| 25. | Crack in south footing of foundation A | 29 |
| 26. | Position of foundations relative to mined-out area on completion of panel | 30 |
| 27. | Vertical displacement contours through foundations | 31 |


BEST COPY AVAILABLE

ILLUSTRATIONS--Continued


| | | Page |
|---|---|---|
| 28. | Site topographic map and section profiles | 32 |
| 29. | Subsidence development curves for four points along panel centerline | 33 |
| 30. | General plot of tilt versus subsidence | 34 |
| 31. | Tilt versus displacement curves for foundations A and B | 35 |
| 32. | Change in tilt over time for center of west wall of foundations A and B | 36 |
| 33. | Changes in tilt direction for foundation A | 37 |
| 34. | Changes in tilt direction for foundation B | 38 |
| 35. | Development of curvature on foundations as they were undermined | 39 |
| 36. | Three-dimensional model of rectangular foundation | 42 |
| 37. | Model of wall in torsion and bending | 43 |


TABLES


| | | |
|---|---|---|
| 1. | Average monthly subsidence rates of foundations | 20 |
| 2. | Change in length between monitoring points on foundations | 40 |
| A-1. | Elevations and vertical displacements of ground surface | 46 |
| A-2. | Elevations and vertical displacements of foundation A | 48 |
| A-3. | Elevations and vertical displacements of foundation B | 50 |
| B-1. | Horizontal movements and directions for site foundations and east-west base line | 52 |
| C-1. | Tilt magnitudes and directions for foundation A | 53 |
| C-2. | Tilt magnitudes and directions for foundation B | 54 |


UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

| | | | |
|---|---|---|---|
| ft | foot | $lb/ft^3$ | pound per cubic foot |
| ft/d | foot per day | pct | percent |
| h | hour | mm/m | millimeter per meter |
| in | inch | yr | year |
| $lb/ft^2$ | pound per square foot | | |

# FOUNDATION RESPONSE TO HIGH-EXTRACTION MINING IN SOUTHERN ILLINOIS

By Larry R. Powell,[1] Theodore L. Triplett,[2] and Ronald E. Yarbrough[3]

ABSTRACT

The Bureau of Mines, in cooperation with the Illinois Mine Subsidence Insurance Fund, instrumented and monitored the response of two foundations to ground movements induced by subsidence from high-extraction retreat mining in southern Illinois. The objective was to study the interaction between the ground surface and a foundation during a subsidence event to enhance the understanding of the mechanisms that produce subsidence effects in structures. This study measured the response of two differently constructed foundations to subsidence, evaluated the capability of the instrumentation and monitoring program to detect and track foundation and ground movements, and provided data for developing mitigative techniques to reduce foundation damage and formulate economic repair strategies.

The instrumentation and monitoring plan successfully measured the response of the foundations to the subsidence-induced ground movements. Both foundations showed a tendency to cantilever, when ground movements were rapid. Curvature developed in the footings as shown by differential vertical displacements and differential tilts. All measured displacements and observed damage indicate deformation was caused by a combination of bending and torsion. The difference in performance of the two foundations indicates that mitigative measures can reduce the effects of subsidential on residential foundations.

[1]Supervisory geologist, Twin Cities Research Center, Bureau of Mines, Minneapolis, MN.

[2]Mining engineer, Twin Cities Research Center.

[3]President, Geo-Technical Associates, Inc., Collinsville, IL.

# INTRODUCTION

Underground mining disturbs the natural equilibrium of the rock mass, thereby causing stress redistribution and associated ground movements around the excavation. In a high-extraction mine, where a substantial area of material is removed, failure of the immediate roof occurs first, then these movements propogate upward through the rock layers to the ground surface where they result in subsidence. The resultant horizontal and vertical displacements can cause damage to surface structures, reduce field access and crop yields of prime farm land, and disrupt or contaminate ground water supplies.

The investigation of mine subsidence and its effects is an active area of research within the Bureau of Mines. The Bureau has been cooperating with the State of Illinois to develop guidelines for underground coal mining methods to maximize coal recovery while preserving surface land uses. Two areas of research in which the Bureau is actively involved are the study of the interaction between the ground surface and the foundation during subsidence-induced ground movements, and the development of cost-effective subsidence monitoring techniques. For this study, the capability of a tiltmeter to detect and follow the movements of the foundations was of interest. Data from these studies will enhance the understanding of the mechanisms that produce foundation damage and will aid in the design of subsidence-resistant foundations and economic repair strategies.

From December 1984 to May 1987, the Bureau and the Illinois Mine Subsidence Insurance Fund monitored the response of two foundations to ground movements induced by subsidence from a high-extraction, retreat, room-and-pillar mine in southern Illinois. The major objective of the research project was to measure the vertical, horizontal, and differential displacements of the foundations and observe the induced damage in response to the surface ground movements caused by mining. This project was not an attempt to completely delineate the subsidence event; rather, two foundations were built above an active mine and the instrumentation was concentrated to measure the ground surface-foundation interactions.

Since 1980, the Illinois Mine Subsidence Insurance Fund has paid more than $5 million to homeowners for subsidence-related damage to structures. The average cost per structure has increased from $18,000 in 1980 to $28,000 in 1985 (1).[4] The feasibility of repairing rather than replacing extensively damaged components is increasing, and the development of standardized, inexpensive repair techniques is becoming economically important. In addition, monitoring of ground and structural movements in mine subsidence events has proven costly because displacements may continue to occur at damaging rates for years. The possibility that a structure may be affected by subsidence more than once must also be considered before repairs are initiated. Just because instability has already occurred in an abandoned partial extraction mine, does not mean additional instability could not occur. Thus, if a structure is to be repaired, it would be economically expedient to repair the structure so that additional mine subsidence events will not affect the structure as much as the original event.

---

[4]Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

Documented case histories of structural damage from ground movements over abandoned mines have been compiled for western Pennsylvania (2) and Illinois (3). However, published information exists on only one other residential structure in the United States that has been monitored over a high-extraction coal mine (4-5). Moreover, little information exists on foundation movements relative to ground movements over active coal mines (6-7). Prediction of differential settlements and damage potential to structures relies on ground surface-structure interactions (8-9). Measurements of differential settlement and horizontal movements on the foundation and adjacent ground are necessary (6, 10).

This study is a start toward understanding how a structure reacts to ground movements caused by high-extraction mining. Data from this study will be utilized by the structural engineering profession to improve foundation designs that will minimize damage. Also, it will expedite the development of repair strategies that will enable structures to be repaired efficiently, quickly, and to better withstand subsequent subsidence-induced movements. Information from this study will also aid in developing mine designs that will reduce the potential damage-causing ground movements.

The Illinois Mine Subsidence Insurance Fund leased 5 acres of land above a high-extraction coal mine in Jefferson County, IL. Two 30- by 40-ft foundations were constructed over the center of a high-extraction retreat room-and-pillar panel. One of the foundations was built using typical construction methods for southern Illinois; the second was built incorporating commonly recommended damage-mitigating techniques (11-12). The foundations and surrounding ground surface were monitored for horizontal, vertical, and differential movements. Access to the site was obtained in March 1984; the foundations were built during August of that year; and monitoring was initiated in December 1984 and continued until May 1987.

## ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of Rebecca Ford, mathematician, Twin Cities Research Center, for computer programming, tiltmeter data reduction, and computer graphics support. Edmund Murphy, general manager, Illinois Mine Subsidence Insurance Fund, is recognized for coordinating site access and providing support for foundation construction and instrumentation. We thank Jerry Zmudzinski, mining engineer, Inland Steel Corp., for providing daily mining progress throughout the monitoring program. We also acknowledge Dianne Kay, civil engineer, M.B. Corlew and Associates, Edwardsville, IL, for foundation design specifications, and Philip Shafer and Fred Hunter, Lawrence Lipe and Associates, Benton, IL, for assistance with surveying.

## SITE DESCRIPTION

The study site is located over a high-extraction coal mine located near Sesser, IL (fig. 1). The site is located in the Mount Vernon Hill Country physiographic division of Illinois which is part of the Till Plains section of the Central Lowland province. The bedrock surface is a maturely dissected, sandstone-shale plain of low relief that is covered by less than 40 ft of Illinoian drift (13). In some areas it is overlain by 25 to 50 in of loess (14). Topography at the site is gently rolling with maximum relief of 21 ft.

BEST COPY AVAILABLE

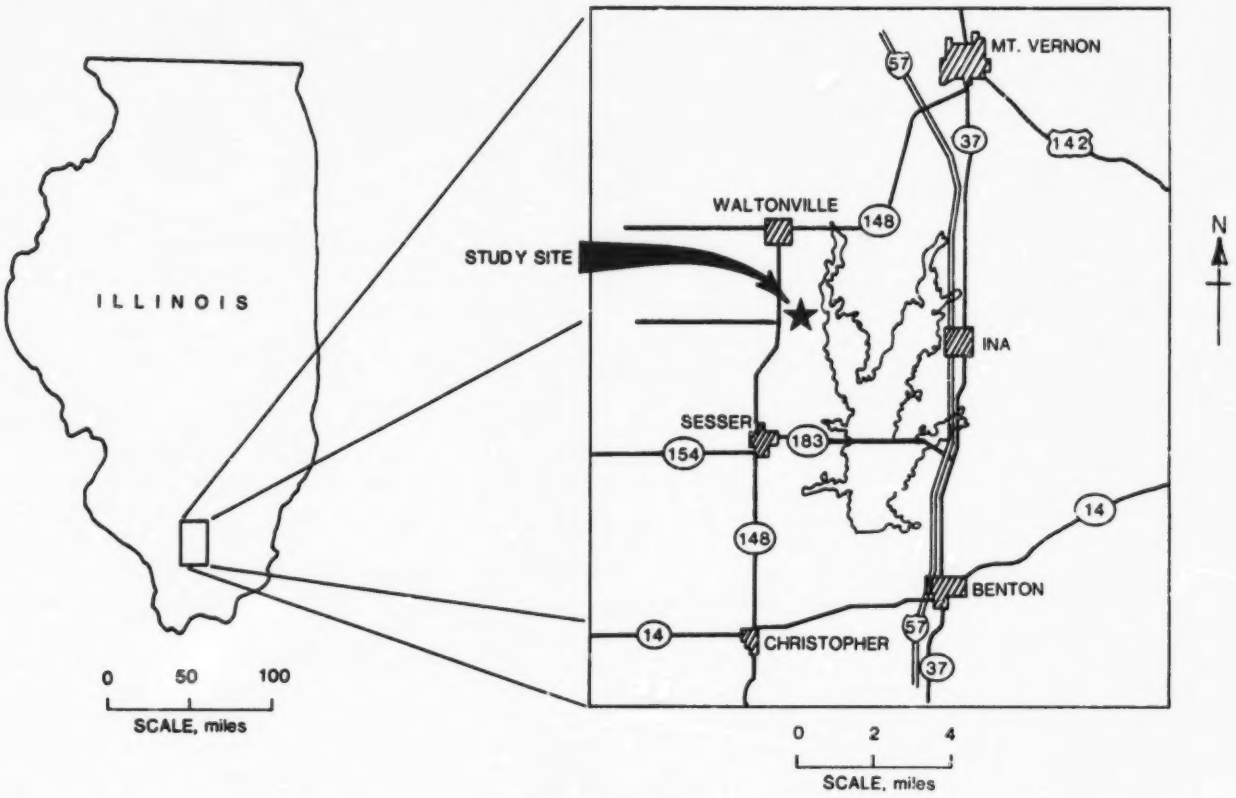


**FIGURE 1.–Site location.**

The bedrock underlying the site is composed of rocks of the Carbondale and Modesto Formations of the Pennsylvanian System. These formations are composed primarily of shales and siltstones with small quantities of sandstone and limestone. Figure 2 represents an east-west geologic cross section through the study area. The bedrock is composed of about 82 pct shale and siltstone, 15 pct sandstone, and 3 pct limestone. The mine operates in the Herrin (No. 6) coal at a depth of about 720 ft; the coal averages 8.9 ft thick.

Structurally, the study site is located between the Rend Lake Fault System to the east and the DuQuoin Monocline to the west near the southern margin of the Illinois Basin (15). The Rend Lake Fault System is expressed by a prominent syncline that runs north-south approximately 2 miles northeast of the site. Displacements on individual faults within the system are less than 55 ft (15).

## MINING PRACTICES

The mine extracts between 7.5 and 8 ft of coal. The panel directly under the foundations is oriented north-south, is 3,200 ft long and 300 ft wide. Because chain pillars on both sides of the panel are also extracted, the total extraction zone is 480 to 500 ft wide. Figure 3 shows a general layout of the panel in relation to the surrounding extraction panels and entries. The panel to the east was completed in August 1984; the panel beneath the foundations was mined from May 1984 to February 1985; and the panel to the west, which also affected the site, was mined from December 1984 to September 1985.

The extraction system utilized is a high-extraction retreat mining system commonly known as the Old Ben mining method (16). To fully understand the

BEST COPY AVAILABLE



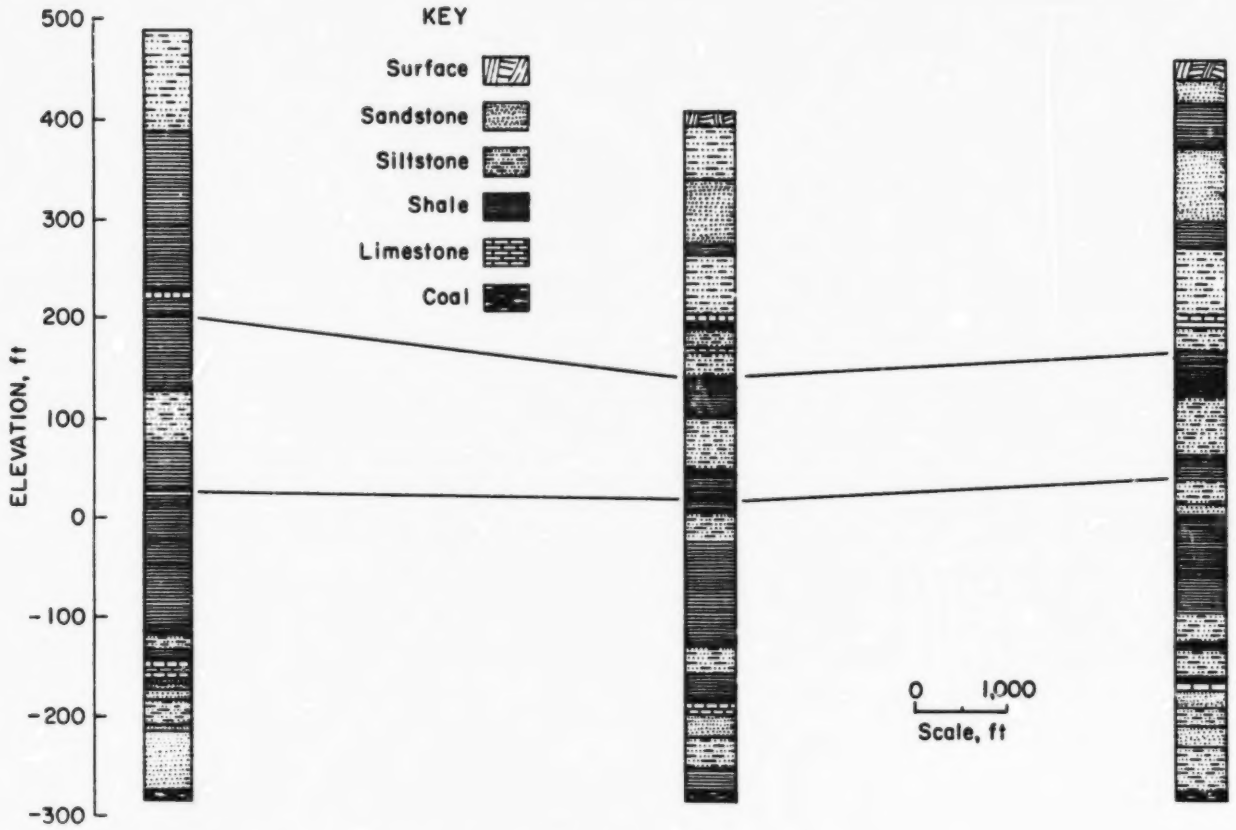


**FIGURE 2.–East-west geologic cross section.**

nature of the ground movements that the foundations experienced, the details of this mining method must be understood. At the study site, panels approximately 300 ft wide are outlined with four entries; the panel entries are 15 ft wide and are on 60-ft centers. Crosscuts are made every 74 ft, thus forming 45- by 59-ft pillars. The panel is then mined on retreat by a repetition of two steps. First, the panel is mined utilizing room-and-pillar techniques resulting in 40- by 85-ft production pillars. Before these pillars are second mined, another row of pillars is developed. The first row of pillars is then extracted using remote-control continuous mining machines. This process continues from north to south until the panel is completed. In addition, one row of chain pillars on the east and two rows of chain pillars on the west are mined as the panel is retreated. Approximately 85 pct of the coal is removed. No permanent pillars are left for support. The stumps and fenders, which cannot be recovered because of safety factors, crush out immediately.

As the panel is retreated, the development of rooms and the extraction of pillars does not occur along an exact east-west line. As shown in figure 4, pillar extraction in the eastern half of the panel is ahead of pillar extraction in the western half. Therefore, retreat occurs from the north to south but extraction occurs at an angle to the retreat line. Figure 4 also shows that the pillar extraction schedule can change the face orientation as mining continues. This changing face orientation and the previous mining to the east greatly influenced the direction from which the ground movements approached, and the foundations reacted as if the mining approached from the northeast.

BEST COPY AVAILABLE

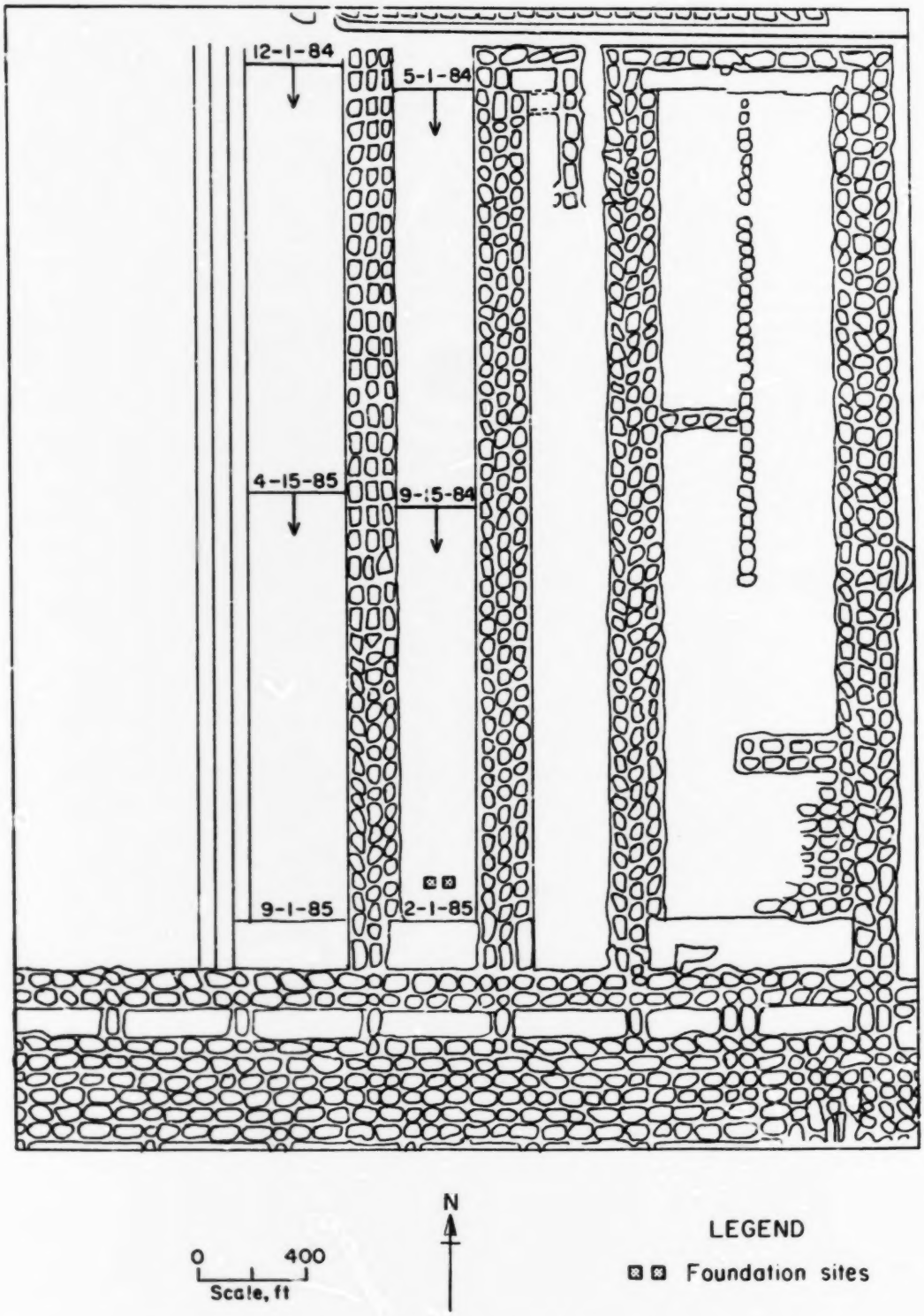


**FIGURE 3.–General mine map. Dates indicate position of face.**

BEST COPY AVAILABLE



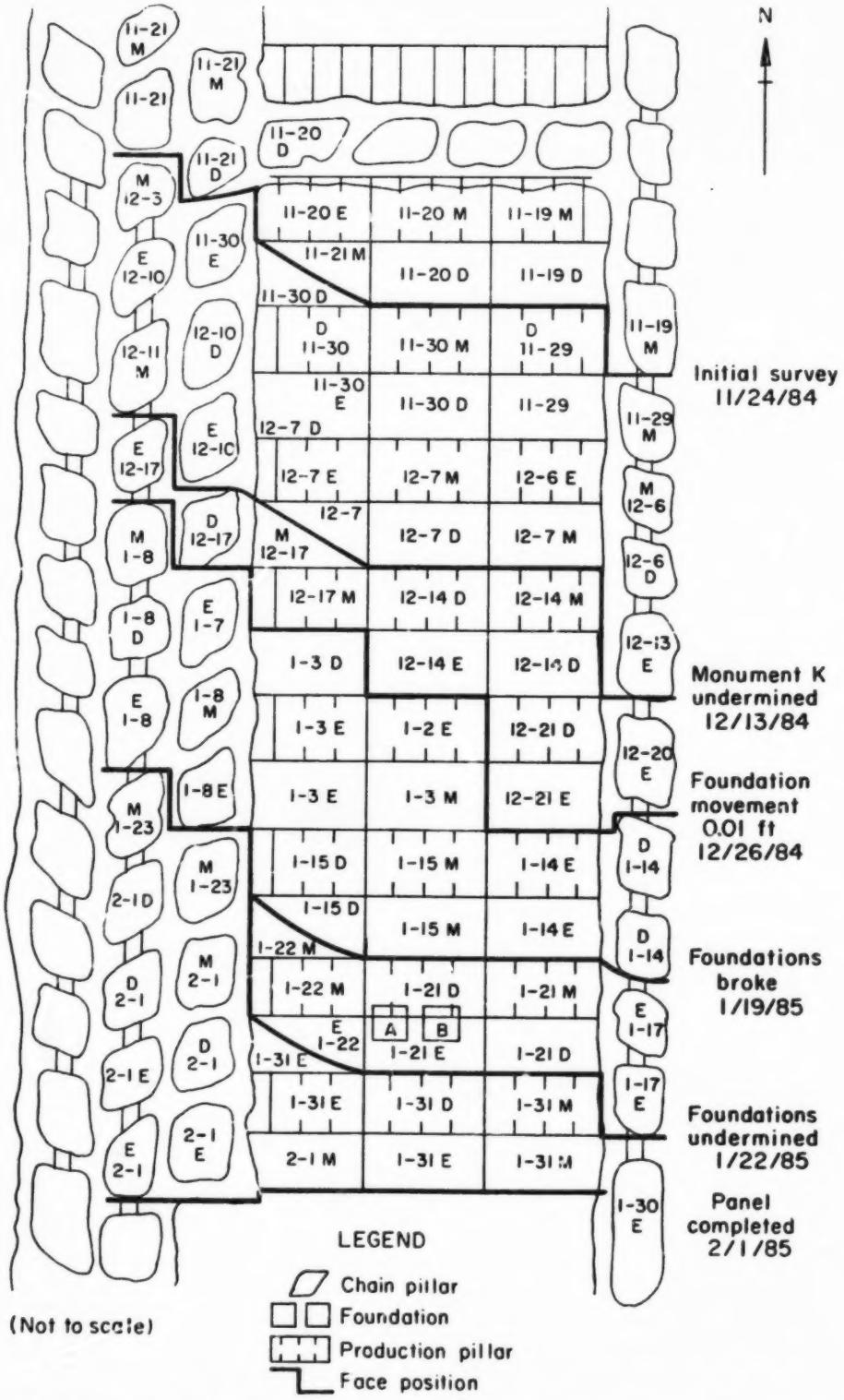


**FIGURE 4.–Mining schedule highlighting selected face positions. The month, day, and shift that a pillar was mined is indicated. M, midnight; D, day; and E, evening.**

BEST COPY AVAILABLE

## FOUNDATION DESIGN

Two 30- by 40-ft foundations were constructed about 150 ft north of the south end of the panel; each was oriented with its long axis in a north-south direction, parallel to the mined panel. Because one objective of the study was to determine the effectiveness of commonly recommended subsidence mitigating techniques, each foundation was constructed differently (fig. 5). Foundation A was built utilizing construction practices common in Illinois, and foundation B was modified to reduce the effects of subsidence-induced ground movements. This arrangement allowed a direct comparison of foundation response between the two foundations.

In Illinois, the most common foundation configuration is a 2-ft foundation wall constructed of concrete block laid on an unreinforced concrete strip footing (17); therefore, foundation A was constructed with this type of foundation. The strip footing consisted of poured concrete 16 in wide and 10 in thick. Three courses of 8-in concrete block were placed on the footing; a sill plate was placed on top of the concrete block; and 2- by 10-in floor joists were placed on 16-in centers in an east-west orientation. A main beam of three 2- by 10-in boards nailed together was run in a north-south direction down the center; this beam was supported by three evenly spaced, 3.25-ft-high steel columns that rested on 1- by 1- by 0.5-ft concrete pads.

Foundation B was constructed using design modifications that originated in Europe (11-12). Not all mitigation techniques apply to crawl-space foundations, but certain concepts that have general applicability were incorporated into the design of the foundation. For instance, friction and adhesion at the soil-foundation interface results in structural deformations as the tension wave moves through the structure. To counteract this mechanism, a 28-in-wide trench, formed with 2- by 6-in rail, was filled with 6 in of mechanically compacted, clean sand. The compacted sand was then smoothed and covered with a 0.004-in-thick polyethylene sheet, and the concrete footing was poured on this base. The three main beam support footings were also given the sand layer and polyethylene sheet treatment. The polyethylene sheeting and sand layer allow the footing to slide, thus friction is reduced at the soil-foundation interface.

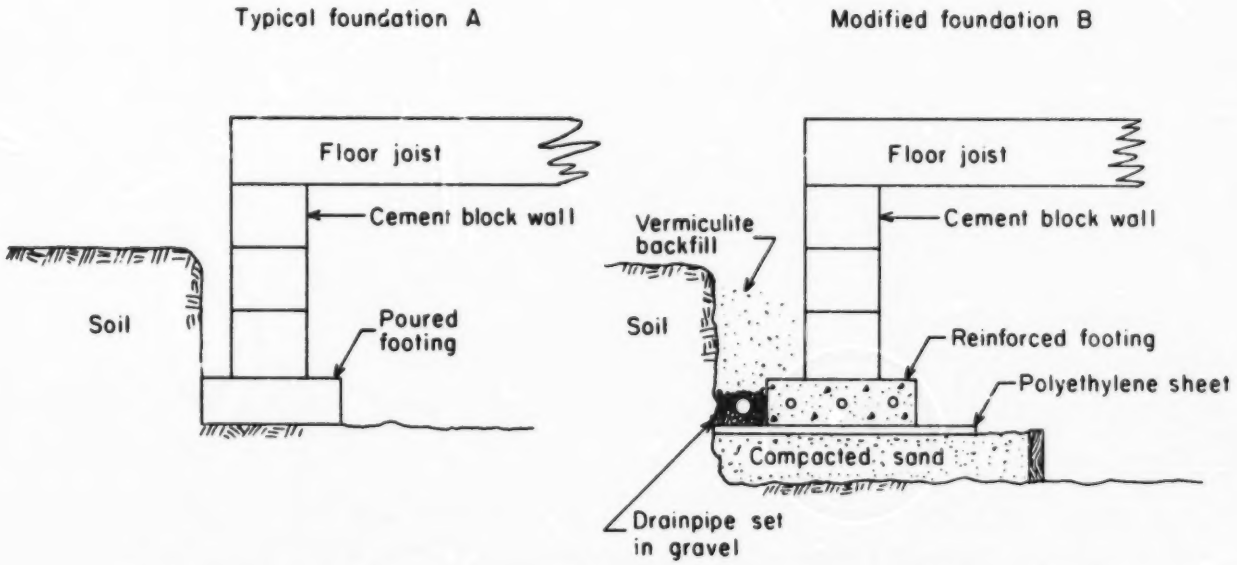


**FIGURE 5.–General difference between typical foundation A and modified foundation B.**

BEST COPY AVAILABLE



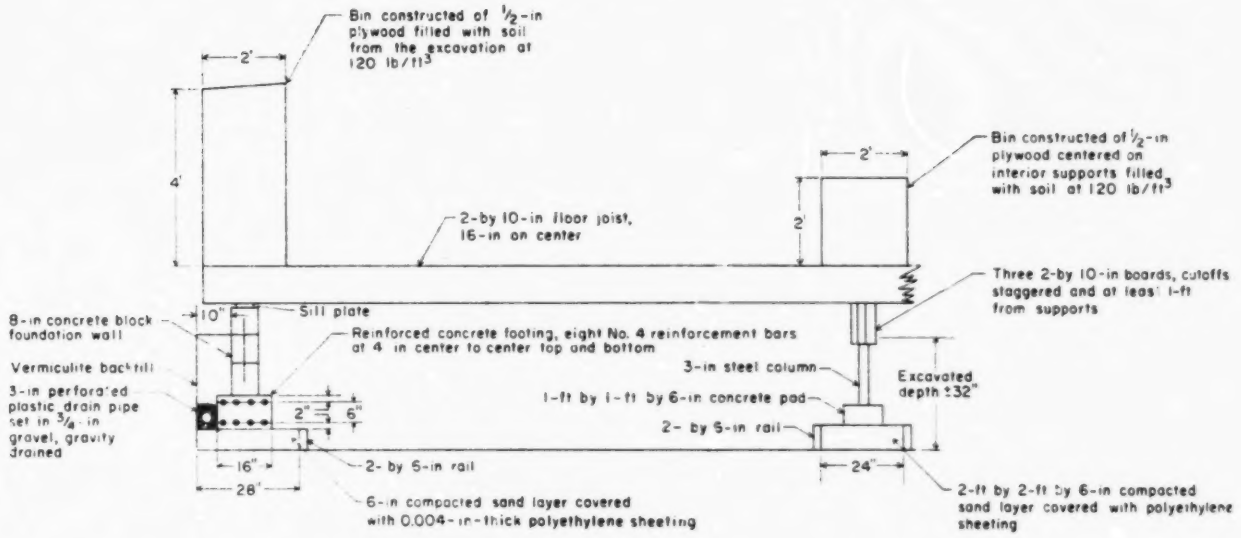
Bin constructed of ½-in plywood filled with soil from the excavation at 120 lb/ft³
2'
4'
2-by 10-in floor joist, 16-in on center
2'
2'
Bin constructed of ½-in plywood centered on interior supports filled with soil at 120 lb/ft³
Three 2-by 10-in boards, cutoffs staggered and at least 1-ft from supports
8-in concrete block foundation wall
10"
Sill plate
Reinforced concrete footing, eight No. 4 reinforcement bars at 4 in center to center top and bottom
Vermiculite backfill
3-in perforated plastic drain pipe set in ¾-in gravel, gravity drained
2"
6"
3-in steel column
1-ft by 1-ft by 6-in concrete pad
Excavated depth ±32"
2- by 6-in rail
16"
28"
2- by 6-in rail
24"
6-in compacted sand layer covered with 0.004-in-thick polyethylene sheeting
2-ft by 2-ft by 6-in compacted sand layer covered with polyethylene sheeting

**FIGURE 6.–Construction and bin location details for modified foundation B.**

The footing of foundation B is 10 in thick and 16 in wide. To further increase the resistance of the foundation to tensile stresses, eight No. 4 reinforcement bars were placed in the footing in two layers 6 in apart. The bars were layed across each other at the corners. To reduce the compressive stresses transmitted to the footing and foundation wall, a backfill trench was excavated around the foundation. A 3-in-diameter perforated plastic drain pipe was set in 0.75-in gravel at the top of the compacted sand layer to remove surface water in the backfill. The trench was backfilled with uncompacted, horticultural grade vermiculite. Other than these three modifications, the construction of foundation B followed exactly that of foundation A. The modifications resulted in a $2,400 increase in construction cost over foundation A, mostly in increased time and labor.

To simulate the load of a typical one-story, wood-framed structure and contents, 12 bins were placed around the perimeter of each foundation. On the east and west footings the bins were 4 ft high, 2 ft wide and 8 ft long. On the north and south footings they were 12 ft long. Bins 2 by 2 by 2 ft (fig. 6) were placed over the steel columns supporting the main beam. The bins were centered over the foundation walls and filled with soil to simulate a footing stress of approximately 595 lb/ft$^2$.

## MONITORING PLAN

The foundations and ground surface were monitored to detect three of the damage-producing mechanisms caused by mine subsidence: vertical displacements, horizontal displacements, and tilt. In this section, the subsidence monitoring plan is briefly discussed. More details on the instruments used in this study can be found in previous publications (17-20).

Vertical displacement was measured with a Wild[5] NA-2 automatic level with a Wild GPM3 parallel plate micrometer with a compensator accuracy of ±0.3 in and an internal reading to 0.0001 ft. A Wild

[5]Reference to specific products does not imply endorsement by the Bureau of Mines.

BEST COPY AVAILABLE

GPLE 10-ft invar leveling staff was used to complement the level. Closure error with this instrumentation was held to a tolerance of 0.003 ft. Maximum length of site allowed was between 150 and 200 ft. Horizontal displacements were measured with a Wild T-1 theodolite and a tape to a tolerance of 0.01 ft.

Ground surface displacements were measured on frost-free monuments. The monuments were placed by digging a 3-ft-deep, 6-in-diameter hole with a hand auger. A 3-ft-long, 6-in-diameter polyvinyl chloride (PVC) pipe was driven as a side wall. A 5-ft-long, 0.5-in-diameter reinforcement bar was driven down the center of the hole to approximately within 1 in of the ground surface. The hole was backfilled with 2.5 ft of sand, and 6 in of vermiculite was added on top of the sand for insulation. The PVC pipe was then capped.

A base line was established from a benchmark located on a concrete headwall south of the site (fig. 7). The elevation of the benchmark was brought in from the mine's main shaft collar. A line of monuments was established from the headwall to an east-west base line, 800 ft north of the headwall. A 1,000-ft east-west line was established across the panel along which monuments were spaced 100 ft apart. These monuments consisted of 4-ft lengths of reinforcement bar. A frost-free (protected from frost heave effects) monument was placed on the centerline of the panel along this base line and the north-south base line was extended 330 ft northward between the foundations along the centerline of the panel. Additional monuments were centered 7 ft north of each foundation.

Measurement of horizontal and vertical displacements on the foundations was accomplished by using eight survey points placed on the top of each footing. These points, situated at the corners and midpoints, consisted of 0.5-in-diameter, flat-top stove bolts embedded into the footing before the concrete set (fig. 8). To detect foundation extension, a metal tape with a pull gauge was used to measure horizontal distances between eyebolts cemented into the corners of the foundation. Measurements were made along the walls and diagonally across the structures.

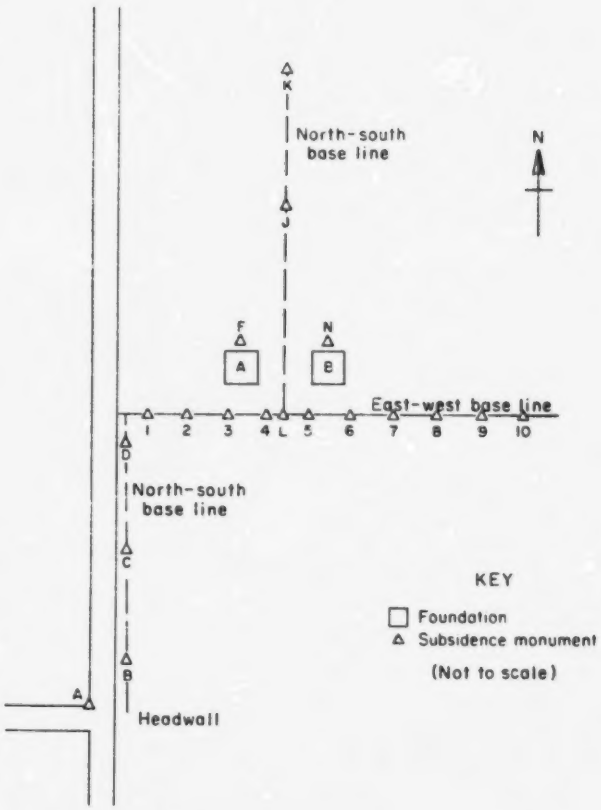


**FIGURE 7.–Survey site network showing position of subsidence monuments on north-south and east-west base lines (17).**

Tilt in the foundations was measured with a Digitilt tiltmeter system. This system consisted of a portable tiltmeter sensor, a digital indicator, and ceramic tiltplates (fig. 9). The tiltplates were permanently attached to the top of the footings at selected positions (fig. 8) using epoxy cement.

All monuments were emplaced and baseline measurements made well in advance of the inception of ground movement. Initial monument positions were established in November 1984, when the mining face was approximately 800 ft north of the

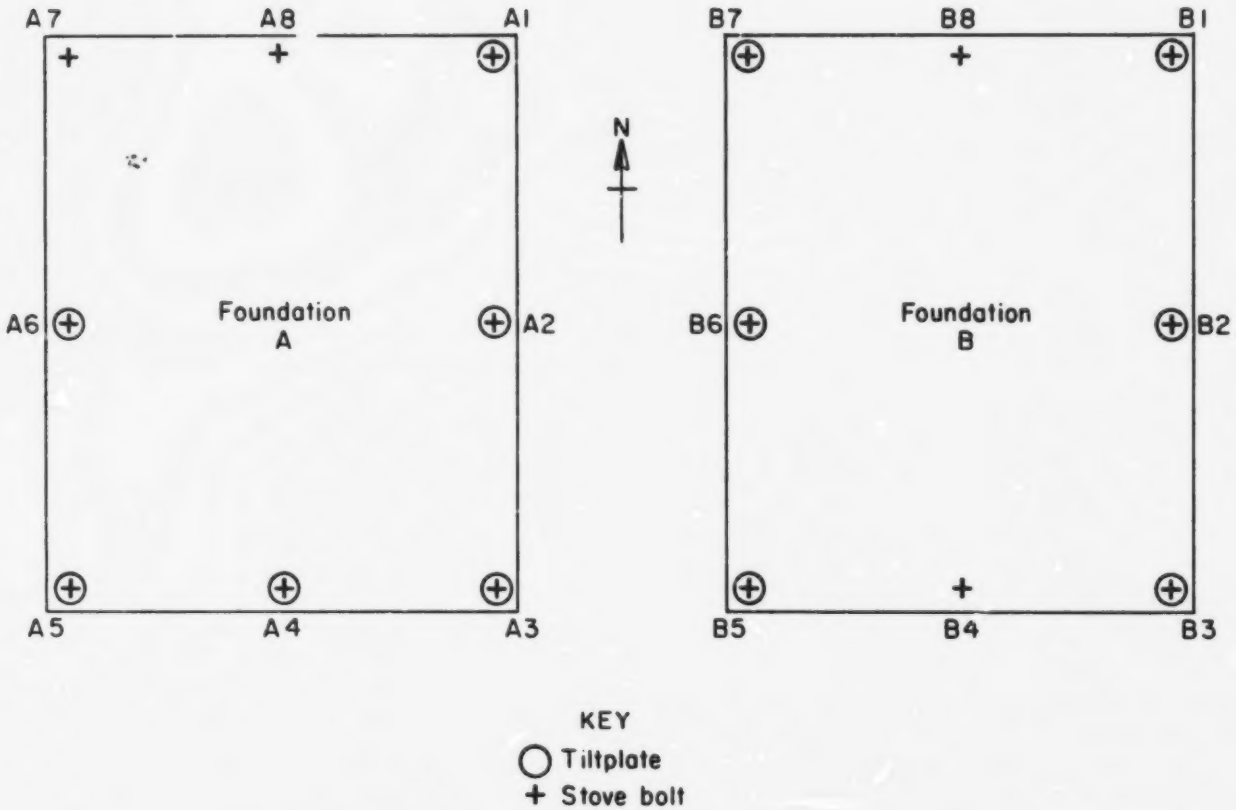


**FIGURE 8.–Location of survey points and tiltplates on foundations (18).**

structures. Movement on monument K, 270 ft north of the foundations, was first detected in early December 1984. All points were then monitored on a daily basis in January and the first half of February 1985, because the greatest amount of movement was expected during that period. Surveys were conducted once a week through February and every 2 weeks from March through June. Monthly monitoring began in July 1985 and continued through February 1986. Monitoring was done every 3 months through May 1987. Horizontal movements were measured in February and July 1985, and in October 1986. In addition to the base line monuments, vertical displacements were obtained on a 100-ft grid over the entire site in April 1985 and October 1986 to facilitate the making of a topographic map of the area.

## GROUND SURFACE MOVEMENTS

### VERTICAL DISPLACEMENTS

Vertical displacements were obtained on a daily basis once the face advancement began to influence the foundations. This occurred when the face was 400 to 450 ft away. Figure 10 shows the subsidence along the north-south survey line which runs between the foundations from point K in the north to point L in the south.

Several significant dates should be noted. Movement began on the foundations on December 26, 1984, ranging from 0.001 ft on the southern ends to 0.015 ft on the northern ends of the foundations. Both foundations failed on January 19,

BEST COPY AVAILABLE

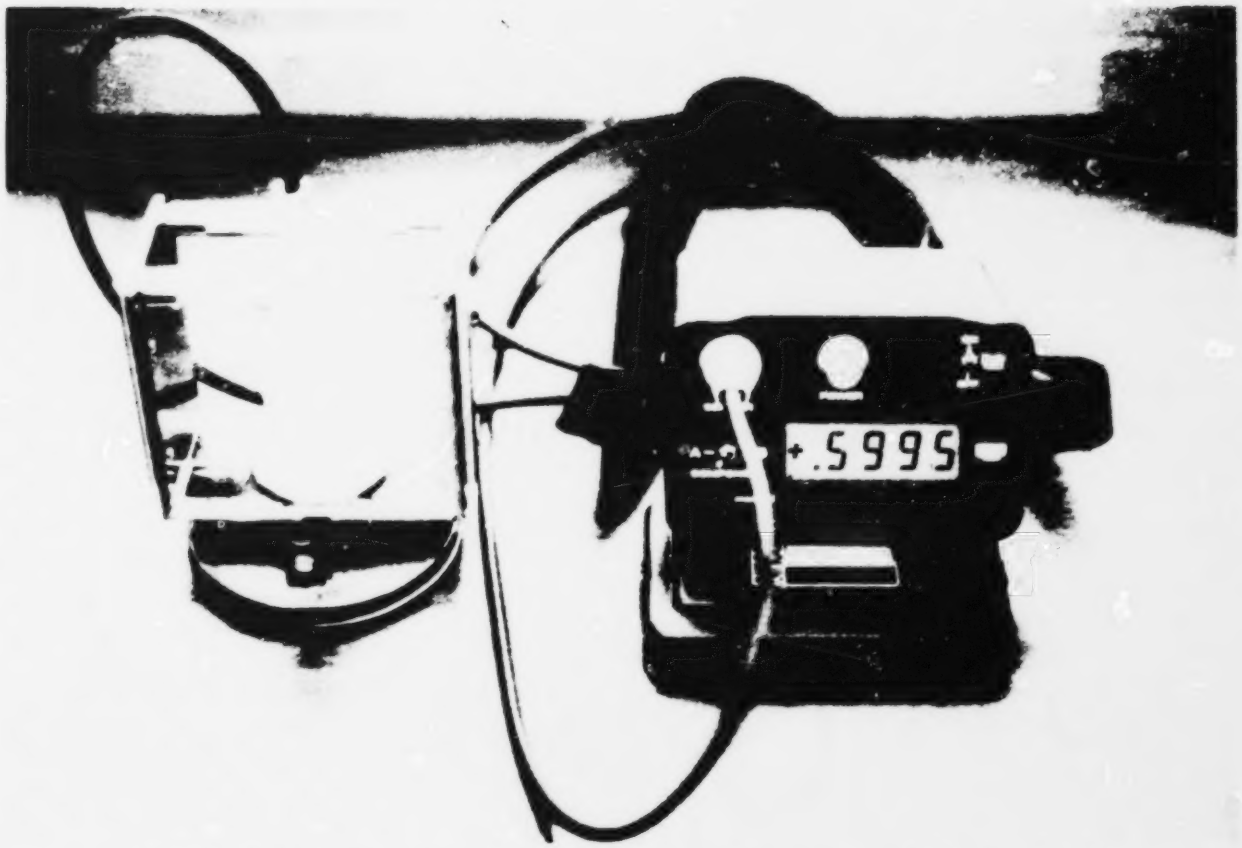


FIGURE 9.–Tiltmeter system showing ceramic tiltplate, sensor, and digital readout.

1985, by cracking in the northeast corners. Foundation A experienced between 0.062 and 0.128 ft of vertical displacement while foundation B experienced between 0.081 and 0.157 ft. This occurred when the mining face was approximately 100 ft north of the foundations. The foundations were undermined 3 days later. The panel beneath the foundations was completed on February 1, 1985. The foundations were later affected by the mining of an adjacent panel to the west which was completed on September 1, 1985.

By comparing figures 4 and 10, the increases and decreases in the rate of vertical displacement can be explained. Continued vertical displacements of about 0.12 ft/d occurred until January 16, 1985, as the working face steadily approached the foundations. From January 16 to 21, the working face did not advance, and the rate dropped to about 0.076 ft/d. In 1 day, the foundations were undermined to a point 50 ft south of their position. The face did not move for 10 days and the average daily rate of displacement dropped to 0.036 ft/d. The remaining 200 ft of panel was completed within 2 days, during which the greatest single day displacement of 0.941 ft occurred at monument J. From February 1 to June 1, 1985, the rate of subsidence dropped to 0.004 ft/d. Then as the influence of the mining of the panel to the west increased, the rate increased to 0.006 ft/d. Between September 1985 and May 1987, residual subsidence of about 0.0003 ft/d occurred.

To determine how well the foundations followed vertical ground movements, the subsidence at the center of the north wall of each foundation was compared with the subsidence at a monument positioned 7 ft north of the wall. To depict this relationship, the change of subsidence between each reading was calculated

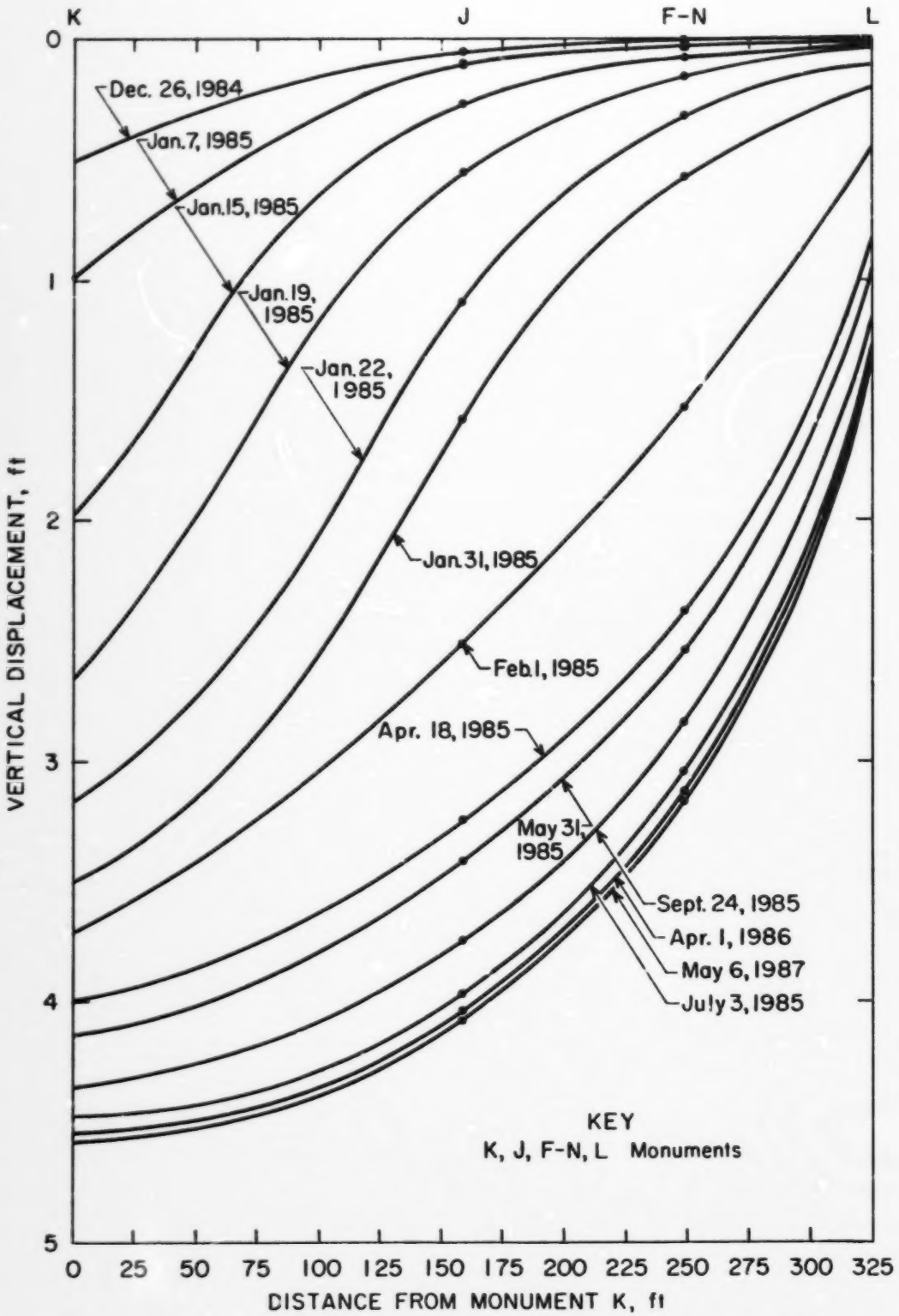


**FIGURE 10.–Change in north-south subsidence profiles with time. The foundations cracked on January 19, 1985 and the panel was completed on February 1, 1985.**

and plotted for each foundation. If the foundations and the ground surface moved at the same rate, the data should fall on a 45° line. However, figure 11 shows that this was not the case for either foundation. It is evident that the foundations cantilevered slightly, particularly when the rate of movement was great. During these periods, the ground surface moved faster than the foundations.

The greatest amount of difference in movement occurred on February 1 for both foundations when foundation A lagged the ground surface by 0.044 ft and foundation B lagged by 0.053 ft. As shown on figure 11, both foundations also significantly lagged the ground surface in July.

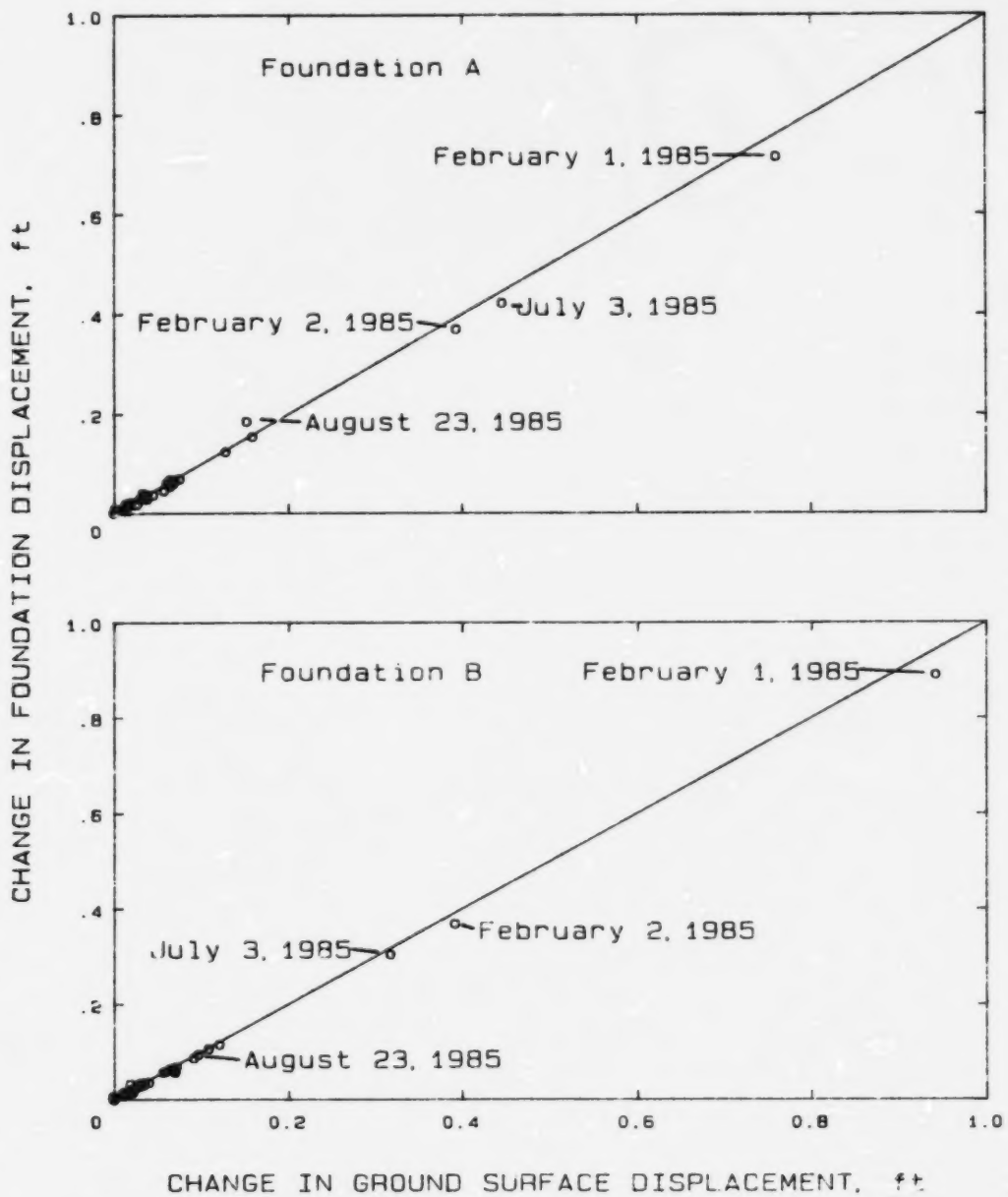


**FIGURE 11.–Relative displacements between ground surface and foundations.**

During this month the panel to the west was beginning to influence the site. As expected, foundation A responded more to the mining of the western panel than foundation B, which showed a greater response to the initial undermining in February than A. The apparent anomalous greater movement of foundation A than the ground surface in August may have been due to the fact that, by this time, the foundation was broken into 10 pieces and the north wall segment may have been floating; thus readjusting independently of vertical ground movements. During 1986, when all mining influence in the area had ceased, modified foundation B had shown less fluctuation in movement than foundation A.

Figure 10 shows that the foundations have not entered the compression zone. As of May 1987, the foundations had almost passed through the tension zone and presently are near the inflection point of the profile. This is because the foundations are approximately 150 ft north of the end of the panel. As the dynamic wave approached, the foundations began to move when the working face was about 400 ft away, resulting in a traveling angle of draw of about 27°.

## HORIZONTAL DISPLACEMENTS

The study site was surveyed three times for horizontal displacement since the initial survey. Figures 12 and 13 illustrate the changes in horizontal position of monuments at the site and along the east-west base line. Figure 12 shows that most horizontal movement measured from November 1984 to February 1985 was the result of mining the panel beneath the site. Generally, significant horizontal movements were towards the centerline of the panel. However, movements also occurred to the north and east due to the influence of the mined-out panel to the east. Monuments J and K illustrated this influence best because they were farther north of the panel end than the monuments on the east-west base line. Monuments B and C, which were southwest of the panel, may have been showing horizontal movement associated with overburden adjustments over east-west entries which were affected by complete removal of support to the north.

From February to July 1985, most horizontal movements shifted increasingly westward. However, monuments K and J showed decreases in horizontal movements, because the inflection point of the dynamic profile had moved south of these points, reversing the direction of horizontal movement. In effect, this decreased the total movement from their original position. This is especially prevalent in movements of monument K. Horizontal movements of other monuments reflect the influence of the trough shape developing at the southern end of the panel. Movements on the western side of the panel are reflecting the influence of the approach of the next panel from the northwest. On the eastern side, horizontal movements toward the southwest reflect adjustments to the developments of the static trough shape around the end of the panel.

Horizontal movements in October 1986 reflect changes in response to the mining of the panel west of the site, which was completed 1 yr prior to the survey. All monuments moved horizontally to the west. Monuments on the east side of the east-west base line showed significant increases in horizontal movement because they did not move greatly when the site panel was mined. From the centerline of the site panel there is an increase in the westward rotation of the movements. Monuments A, B, and C moved directly west from July 1985 positions.

Figure 13 shows in detail horizontal movements along the east-west base line, which was situated 150 ft north of the panel end. Point *4* is along the centerline of the panel; thus, points *1* and *7* are just beyond the panel edges. Generally, the amount and direction of movement from November 1984 to February 1985, (movement to *X*, figure 13) reflected the mining of the panel beneath the site. Monuments *8* through *10* showed minor horizontal displacements (0.04-0.06 ft) because of their distance from the panel edge.

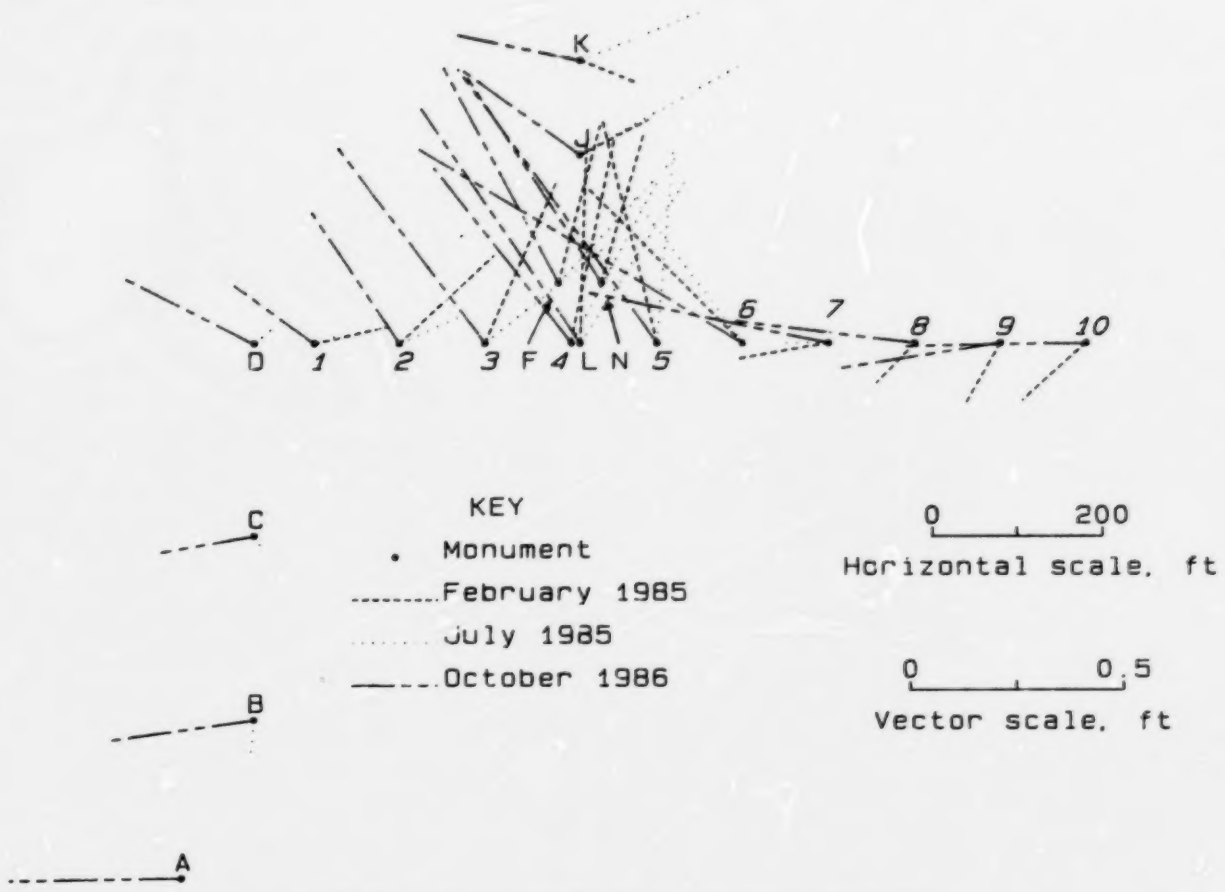


**FIGURE 12.–Horizontal displacements measured at site.**

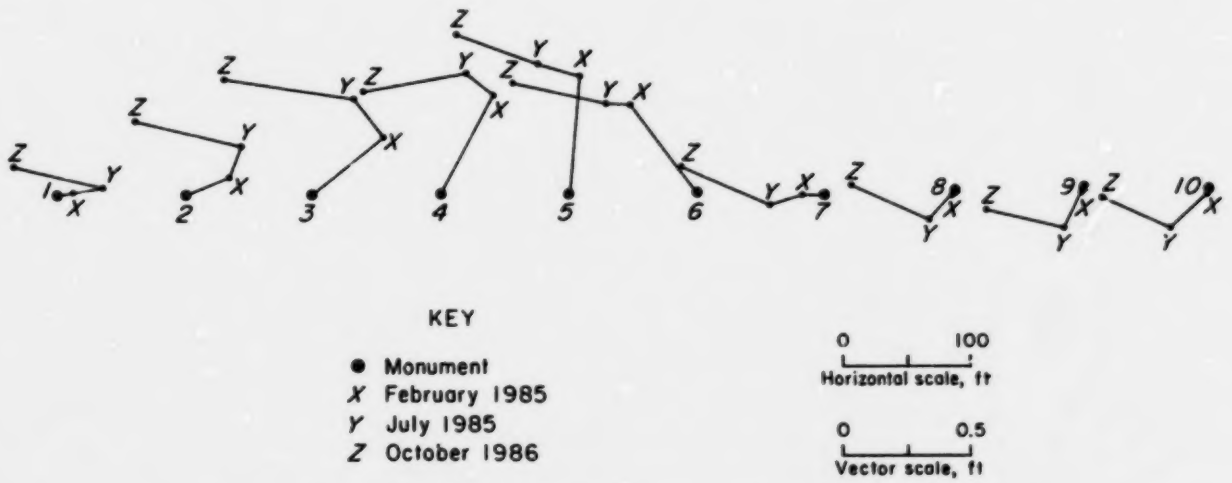


**FIGURE 13.–Horizontal displacements measured on east-west base line.**

From February to July 1985 (*X* to *Y*, figure 13) adjustments were generally in response to the development of the static trough shape at the end of the panel. Eastern monuments beyond the edge of the panel (monuments *7-10*) moved southwestward. Monuments over the mined-out panel generally moved westward, moving more toward the centerline and decreasing toward the edges. Monuments on the western side of the panel (monuments *1-3*) showed increasing amounts of displacement but more northerly direction of movement from November 1984 to July 1985.

By October 1986 (Y to Z) all points were strongly influenced by the mining of the panel west of the site. All resultant directions of movement relative to initial positions were westward. Large horizontal movements of monuments *6* to *10* were the result of the mining sequence. As the panel to the west was mined, the chain pillars on the east side of the panel were removed. Thus, the width of the mined-out area greatly increased. These monuments moved because of readjustments of the surface profile to the wider mined-out area.

## FOUNDATION RESPONSE

### VERTICAL DISPLACEMENTS

Significant vertical displacement (0.01 ft) began on the foundations when the working face was about 400 ft north of the foundations on December 26, 1984. Both foundations initially cracked on January 19, 1985, when the working face was 100 ft away. The foundations were undermined on January 21, 1985, and the panel was completed on February 1, 1985. The foundations are located 150 ft from the end of the panel. Figure 14 shows the vertical position of the foundations as they were surveyed.

Both foundations cracked on January 19, 1985. At this time the maximum displacement on foundation A was 0.128 ft and 0.157 ft on foundation B. As can be seen on figure 15, both foundations exhibited differential vertical displacements, 0.066 ft on A and 0.076 ft on B. This differential vertical movement, coupled with horizontal movements, caused both foundations to experience torsion, which significantly contributed to the position and sequence of their cracking.

The largest vertical movements occurring in a 24-h period occurred when the panel was completed on February 1, 1985, or when the working face was 150 ft south of the foundations. The northwest corner of foundation A dropped 0.767 ft and the same corner of foundation B dropped 0.926 ft. Sixty-four days after daily monitoring stopped, monthly rates of vertical movement were calculated to determine residual vertical displacements. As shown in table 1, vertical displacements dropped to less than 0.07 ft per month. These movements drastically increased during the period May to August 1985, as the panel west of the site began influencing the structures. Rates increased to as much as 0.42 ft per month. Foundation B lagged foundation A in rate increase, possibly because of its more easterly position or its increased strength.

Once the mining of the western panel was completed, residual vertical movements decreased gradually from 0.01 ft per month late in 1985 to 0.003 ft per month 1 yr later. In May 1987, rates decreased even further to about 0.0009 ft per month. During the last 2 yr, when residual movements were being monitored, the rate of vertical movement for modified foundation B was always less than and more uniform than for unmodified foundation A.

### HORIZONTAL DISPLACEMENTS

Horizontal displacements were measured three times on the survey points of the foundations. Figure 16 shows the amount and direction of the horizontal movements. In general, both foundations reacted similarly to the mine geometry and

BEST COPY AVAILABLE

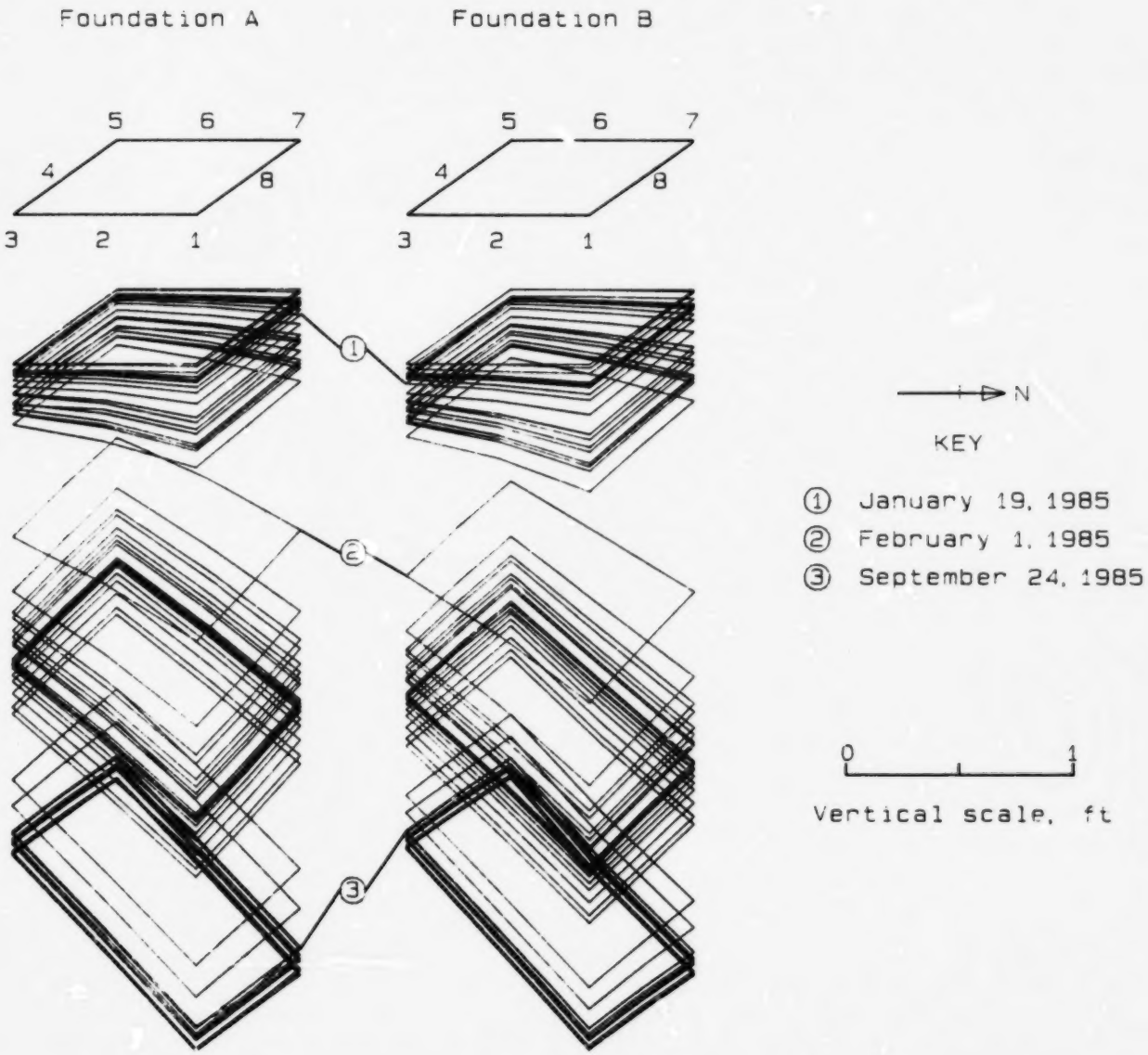


**FIGURE 14.–Vertical displacements of foundations from December 7, 1984, to May 6, 1987. Key dates shown are (1) day foundations cracked, (2) day panel beneath foundations was completed, and (3) day panel immediately to the west was completed. Both foundations were initially level. Numbers refer to survey points on footings as in figure 8.**

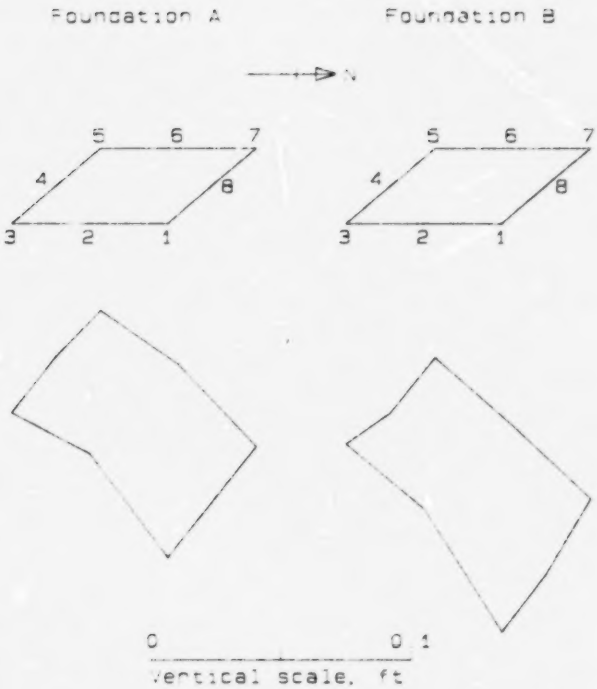


**FIGURE 15.–Differential vertical displacement of foundations when they cracked on January 19, 1985. Numbers refer to survey points on footings in figure 8.**

mining schedule. The position of the survey points in February 1985, shows displacements 15 days after the panel was completed. The foundations moved an average of 0.46 ft with foundation B moving horizontally 0.03 ft more than foundation A. Both foundations moved towards the northeast, 35° for foundation A and 27° for foundation B.

By July 1985, the mining of the panel to the west began to influence the movements of both foundations. Generally, the foundations only moved about 0.13 ft; foundation B averaging slightly more than foundation A. The direction of movement was almost due west; however, foundation A moved in a more northwesterly direction, 299° as opposed to 265° for foundation B. The resultant new positions of the foundations did not appreciably change the amount of displacement from their original positions.

As was the case with vertical displacements, the foundations moved differentially with respect to magnitude and direction of horizontal movement. As shown in figure 17, these differential horizontal displacements caused the foundations to become distorted from their original rectangular shape.

## TILT

Twelve tiltplates were monitored at various fixed positions near the survey points around the footings of the foundations. As the mining face approached from the northeast, the magnitude of tilt slowly increased. Tilt directions were erratic until the mining face was close enough to assert a positive influence on the foundations. Both foundations cracked when the tilts ranged from 0.058 to 0.422 pct.[6] Figure 18 shows tilts as scaled vectors at various points around the foundations spanning the time of failure. In the 24-h period prior to failure, tilts increased only 0.007 to 0.11 pct. As expected, the foundations are tilting towards the northeast, with the northeast area of each foundation tilting more than the southeast; thus, the foundations are experiencing differential tilt, or curvature. The erratic shifts in tilt direction on the southern end of both foundations can be attributed to the combination of differential

[6]0.1 pct tilt equals 1 mm/m.

TABLE 1. - Average monthly subsidence rates of foundations, feet per month

| Foundation survey point | 4/18-5/17/85 | | 5/17-5/31/85 | | 5/31-7/3/85 | | 7/3-7/25/85 | | 7/25-8/23/85 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | A | B | A | B | A | B |
| 1..... | 0.0676 | 0.0598 | 0.0791 | 0.0744 | 0.3576 | 0.2600 | 0.1382 | 0.0941 | 0.1348 | 0.0895 |
| 2..... | .0670 | .0579 | .0720 | .0711 | .3130 | .2312 | .1301 | .0908 | .1288 | .0835 |
| 3..... | .0627 | .0543 | .0659 | .0685 | .2650 | .1981 | .1164 | .0794 | .1205 | .0827 |
| 4..... | .0651 | .0550 | .0650 | .0698 | .2852 | .2141 | .1296 | .0896 | .1370 | .0856 |
| 5..... | .0678 | .0555 | .0659 | .0713 | .3041 | .2320 | .1430 | .0986 | .1582 | .0973 |
| 6..... | .0712 | .0601 | .0731 | .0754 | .3644 | .2753 | .1611 | .1110 | .1693 | .1056 |
| 7..... | .0719 | .0623 | .0798 | .0772 | .4243 | .3097 | .1742 | .1171 | .1772 | .1136 |
| 8..... | .0705 | .0618 | .0794 | .0748 | .3882 | .2809 | .1542 | .1055 | .1522 | .0979 |
| Average... | .0608 | .0583 | .0725 | .0728 | .3377 | .2502 | .1473 | .0983 | .1473 | .0945 |
| | 8/23-9/24/55 | | 9/24-11/12/85 | | 11/12-12/19/85 | | 12/19-1/6/86 | | 1/6-4/1/86 | |
| | A | B | A | B | A | B | A | B | A | B |
| 1..... | 0.0091 | 0.0006 | 0.0152 | 0.0153 | 0.0120 | 0.0118 | 0.0198 | 0.0166 | 0.0130 | 0.0101 |
| 2..... | .0099 | .0042 | .0143 | .0134 | .0112 | .0086 | .0189 | .0191 | .0120 | .0098 |
| 3..... | .0090 | .0067 | .0140 | .0125 | .0081 | .0064 | .0189 | .0113 | .0113 | .0082 |
| 4..... | .0068 | .0027 | .0163 | .0135 | .0085 | .0064 | .0233 | .0198 | .0123 | .0094 |
| 5..... | .0075 | .0022 | .0165 | .0154 | .0118 | .0100 | .0184 | .0140 | .0130 | .0098 |
| 6..... | .0075 | .0015 | .0171 | .0155 | .0139 | .0119 | .0194 | .0184 | .0141 | .0113 |
| 7..... | .0083 | .0023 | .0184 | .0178 | .0138 | .0120 | .0213 | .0189 | .0148 | .0116 |
| 8..... | .0084 | .0006 | .0168 | .0148 | .0136 | .0121 | .0211 | .0178 | .0135 | .0111 |
| Average... | .0083 | .0026 | .0161 | .0148 | .0116 | .0099 | .0201 | .0170 | .0130 | .0102 |
| | 4/1-7/23/86 | | 7/23-10/18/86 | | 10/28-5/6/87 | | | | | |
| | A | B | A | B | A | B | | | | |
| 1..... | 0.0015 | 0.0031 | 0.0018 | 0.0007 | 0.0010 | 0.0007 | | | | |
| 2..... | .0019 | .0031 | .0018 | .0012 | .0010 | .0005 | | | | |
| 3..... | .0025 | .0026 | .0013 | .0016 | .0009 | .0004 | | | | |
| 4..... | .0027 | .0027 | .0014 | .0006 | .0010 | .0007 | | | | |
| 5..... | .0024 | .0034 | .0002 | .0006 | .0021 | .0006 | | | | |
| 6..... | .0034 | .0033 | .0083 | .0008 | .0014 | .0009 | | | | |
| 7..... | .0032 | .0031 | .0087 | .0017 | .0009 | .0004 | | | | |
| 8..... | .0014 | .0030 | .0025 | .0015 | .0010 | .0004 | | | | |
| Average... | .0024 | .0030 | .0033 | .0011 | .0012 | .0006 | | | | |

A Typical foundation. B Modified foundation.

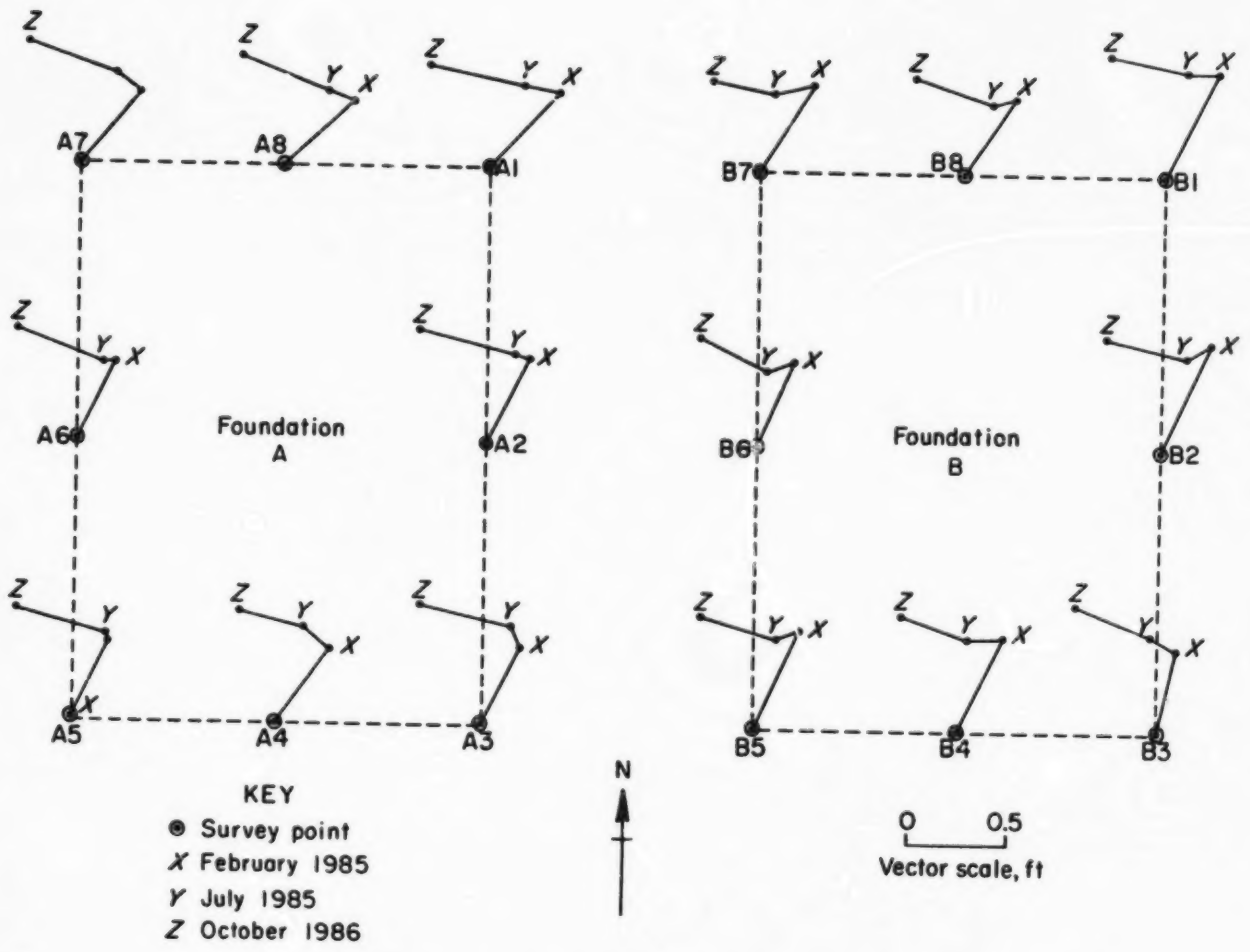


**FIGURE 16.–Horizontal displacement of foundations.**

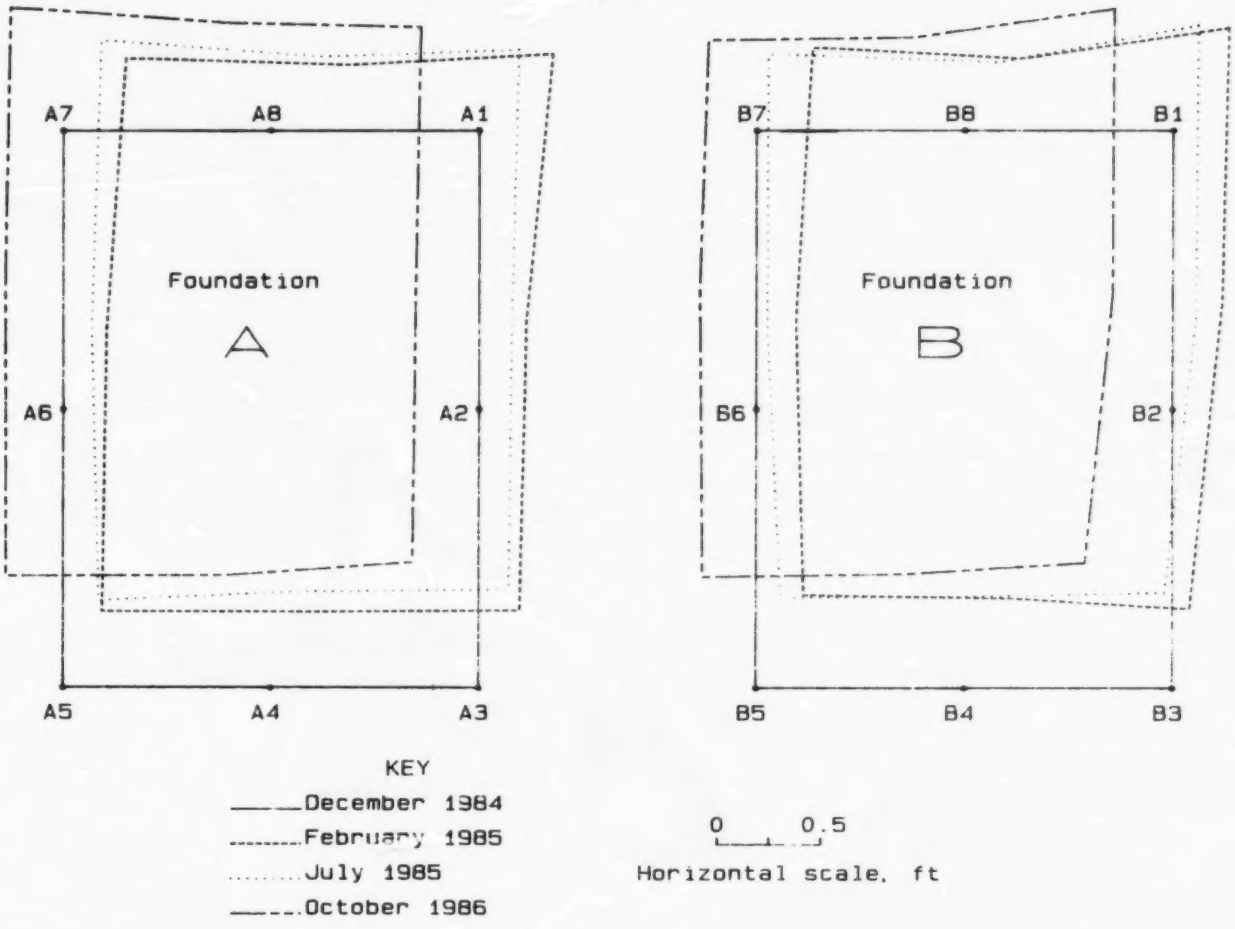


**FIGURE 17.–Foundation distortion caused by differential horizontal movement.**

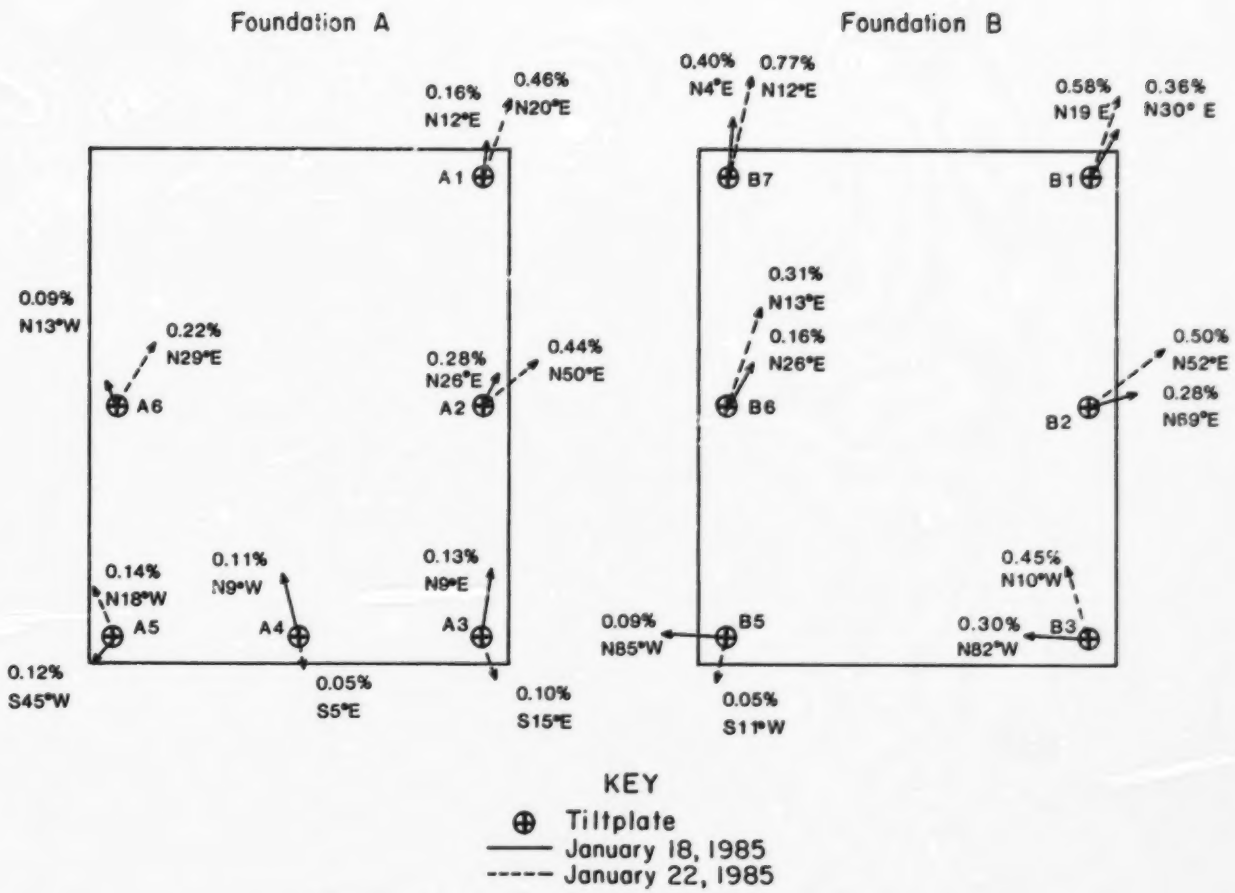


**FIGURE 18.–Magnitude and direction of foundation tilt before and after cracking.**

BEST COPY AVAILABLE

vertical, horizontal, and tilt displacements that the foundations are experiencing. These torsional movements will be discussed later.

Greatest variations in tilt direction occurred on the southern end of the foundations. The fluctuations in tilt direction of all tiltplates decreased as mining advanced beneath the foundations and disappeared when the panel was completed (fig. 19). The northeast corners of both foundations (A1, B1) immediately reacted to the influence of mining; there was very little change in tilt direction prior to the foundations being undermined. The southwest corners (A5, B5), however, showed very large and rapid shifts in tilt direction. As the working face advanced under the foundations, these tiltplates responded and the erratic changes in tilt direction disappeared.

The response of the foundations to the mining sequence can be tracked using the tilt magnitudes and directions. The panel beneath the foundations was completed on February 1, 1985. On this day, the greatest change in tilts were recorded, ranging from 0.60 to 0.74 pct on foundation A and from 0.58 to 0.88 pct on foundation B. During the 3-day period around the completion of the panel, tilts increased from 1.01 to 1.30 pct. This was accompanied by shifts in the direction of tilt toward the northeast, ranging from N 3° E to N 33° E. This northeastward tilt was a result of the orientation of the approaching working face, the influence of the mined-out area to the east, and the fact that chain pillars along the eastern edge of the study panel had also been mined.

Major increases in tilt and shifts in tilt direction again occurred when the adjacent panel west of the site was mined. This panel was completed in September 1985. Because foundation A was influenced more, its response was greater than foundation B. In general, the west

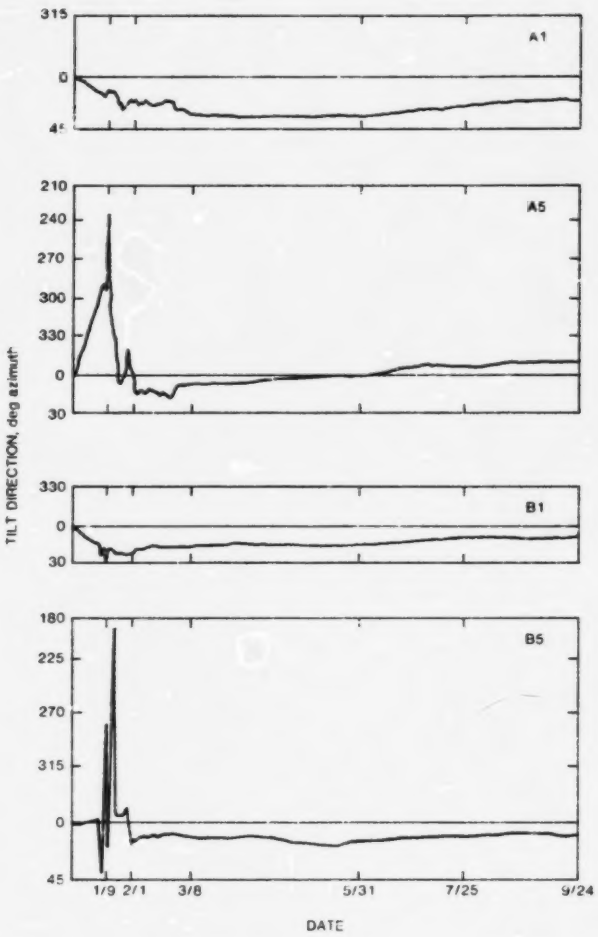


**FIGURE 19.–Tilt direction change for northeast (A1, B1) and southwest (A5, B5) corners of foundations in 1985 (19).**

side of foundation B reacted more than the east side. On the average, foundation A rotated towards the west 2° more than foundation B. Figures 20 and 21 show the changes in tilt over time for foundations A and B, and figure 22 shows tilt directions for selected times to show changes in tilt direction as mining progressed. Because the foundations are located close to the end of the panel, they are permanently tilted, almost due north.

BEST COPY AVAILABLE



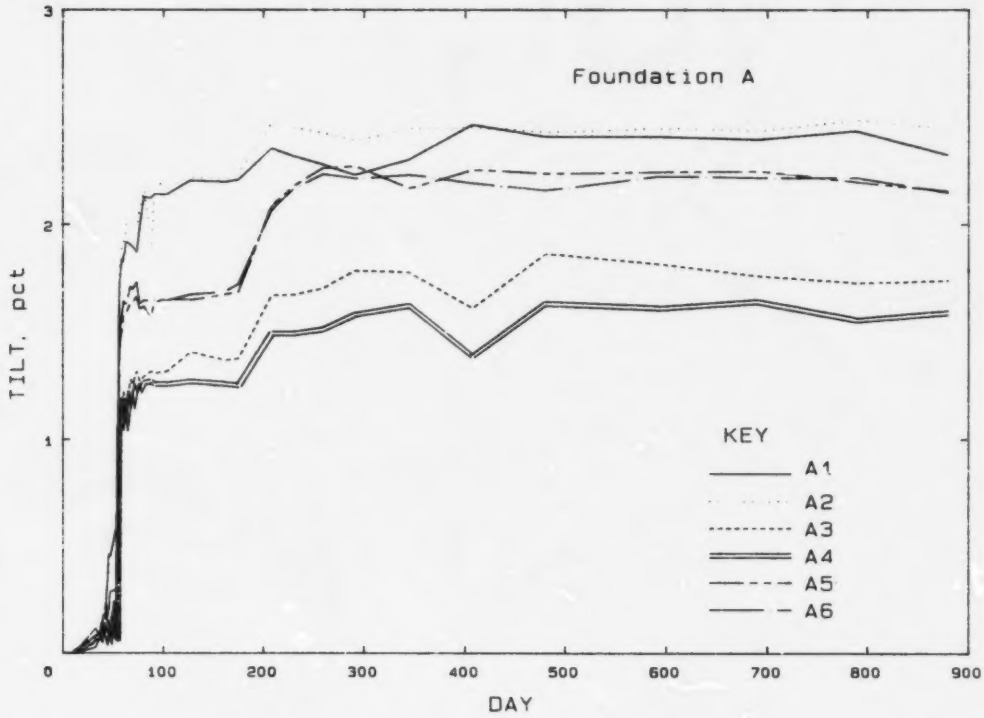


**FIGURE 20.–Change in tilt for typical foundation A.**

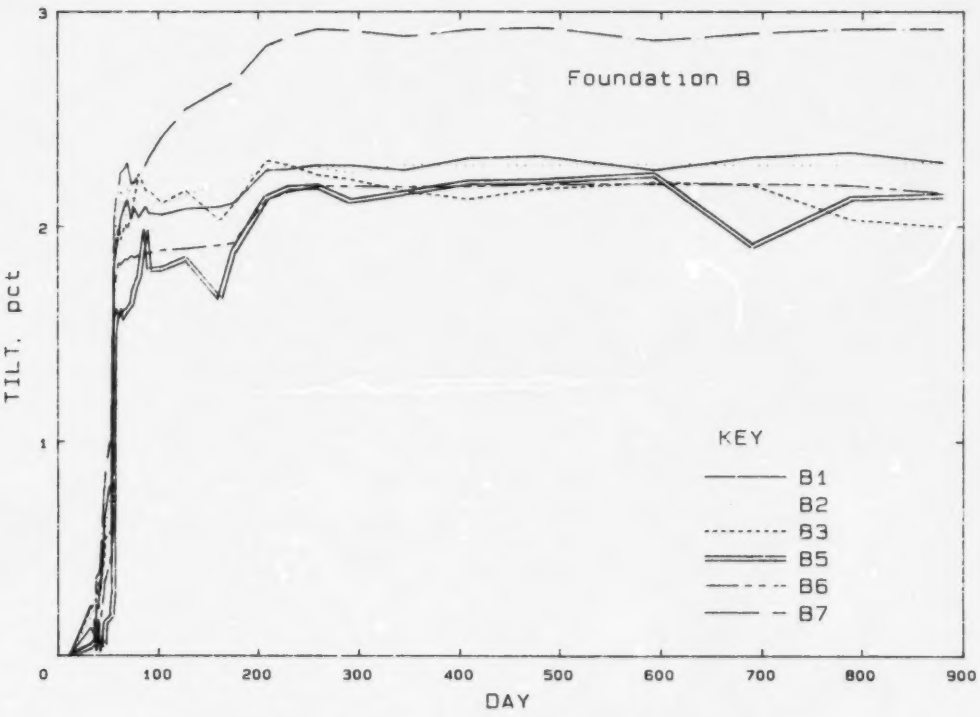


**FIGURE 21.–Change in tilt for modified foundation B.**

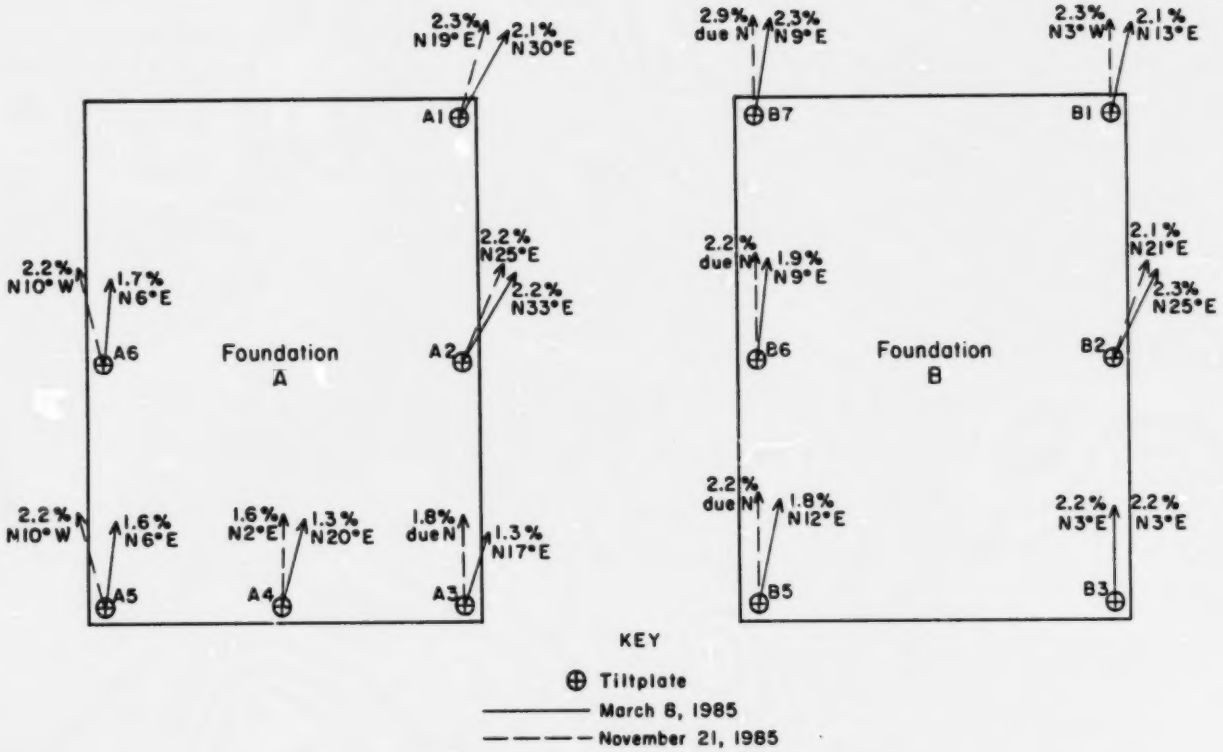


**FIGURE 22.–Tilt before and after adjacent western panel completed.**

## FOUNDATION DAMAGE

The footings on both foundations failed by cracking in the corners on January 19, 1985. Foundation A exhibited a hairline crack in the southeast corner (fig. 23), and foundation B showed a hairline crack in the northwest corner. The maximum vertical displacement on A was 0.1282 ft and 0.1568 ft on B. The differential vertical displacement between A1 and A5 and B1 and B5 were 0.0659 ft and 0.0763 ft, respectively. As the foundations continued to move, more cracks appeared in the footings, first in the corners, then in the north and south walls. Both footings had larger cracks in the southeast and southwest corners. In February 1985, horizontal cracks developed in the east and west walls of both foundations. Figure 24 shows the position of all major cracks and their dates of appearance on the foundations.

Foundation A first showed a crack in the southeast corner on January 19, 1985; 1 day later, all four corners were cracked. These four corner cracks were initially hairline cracks in the footings, but by January 21, all cracks had widened and extended up into the block foundation walls. One week later, all cracks were wider at the top than at the bottom. By February 1, 1985, when the panel was completed, differential widening of the southeast and northwest corner cracks indicated that the south wall was rotating southward and the north wall was rotating northward. At this time, the central beam had moved 1 in southward relative to the south wall. Horizontal cracks appeared on the east and west walls in the mortar joint between the first and second course of cement blocks. These cracks showed inward rotation,

BEST COPY AVAILABLE



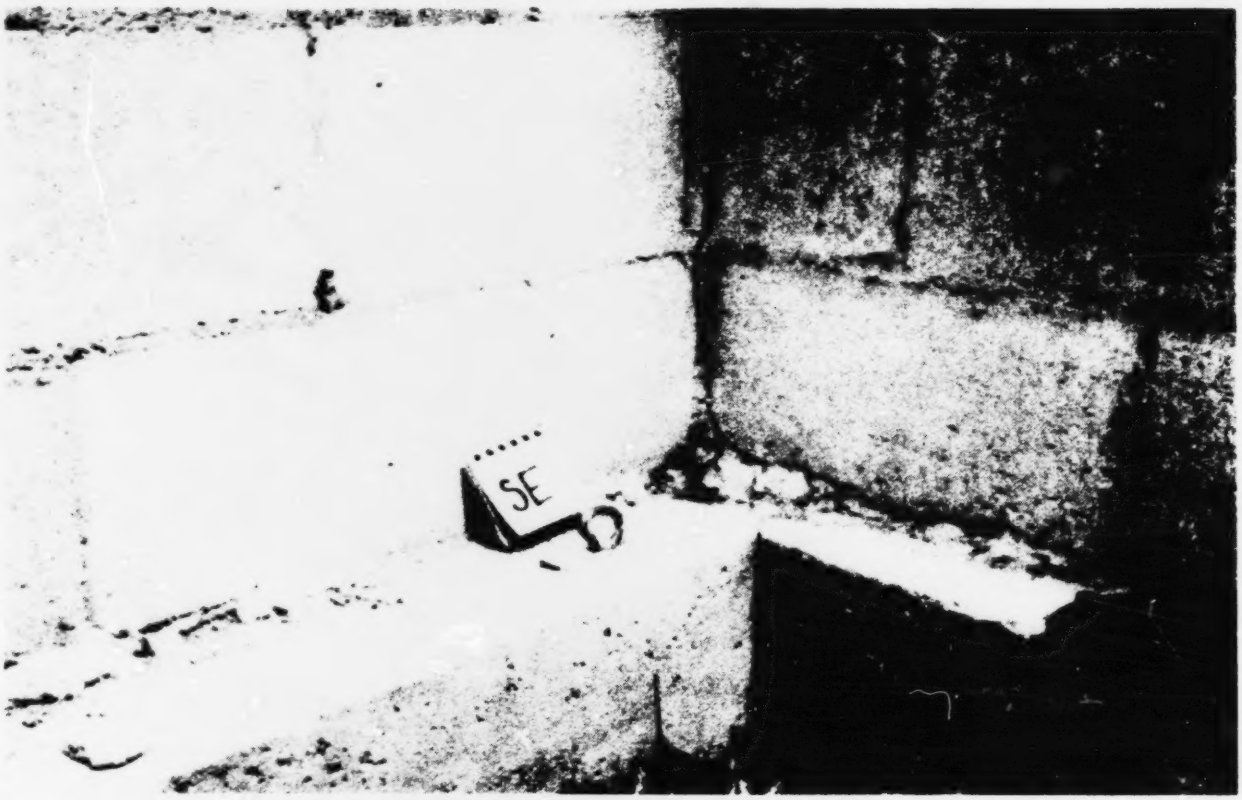


FIGURE 23.–Southeast corner (A3) of foundation A on January 30, 1986.

opening 0.06 in. Vertical cracks began appearing in the north and south footing (fig. 25) within 1 week of the panel being completed.

To date, unmodified foundation A has 10 major cracks in the concrete footing, which range in width from 0.06 to 0.25 in. Also, several of the concrete blocks have been sheared and there is significant cracking along mortar joints both horizontally and vertically. Nine of these cracks appeared during mining of the panel beneath the foundations; one additional crack in the east wall appeared after mining of the panel to the west. Mining of the panel to the west reduced some crack widths by 0.06 in but increased others by as much as 0.16 in.

As in foundation A, modified foundation B also developed a hairline crack on January 19, 1985. This crack appeared in the northwest corner and was followed by the development of a hairline crack in the northeast corner the next day. No additional cracking was observed until hairline cracks developed in the southeast and northwest corners on January 29. By February 2, a hairline crack developed on the north footing and 0.09-in-wide horizontal cracks in the mortar joint between the first and second course of concrete blocks developed in the east and south walls. By this time, the central beam had moved 0.91 in southward relative to the south foundation wall.

By February 4, 1985, movement of the central beam of foundation B had increased to 1 in. Ten hairline cracks were observed, approximately evenly spaced, along the north footing, and one hairline crack developed on the east end of the south footing. By February 6, the central beam had moved an additional 0.06 in and three new hairline cracks

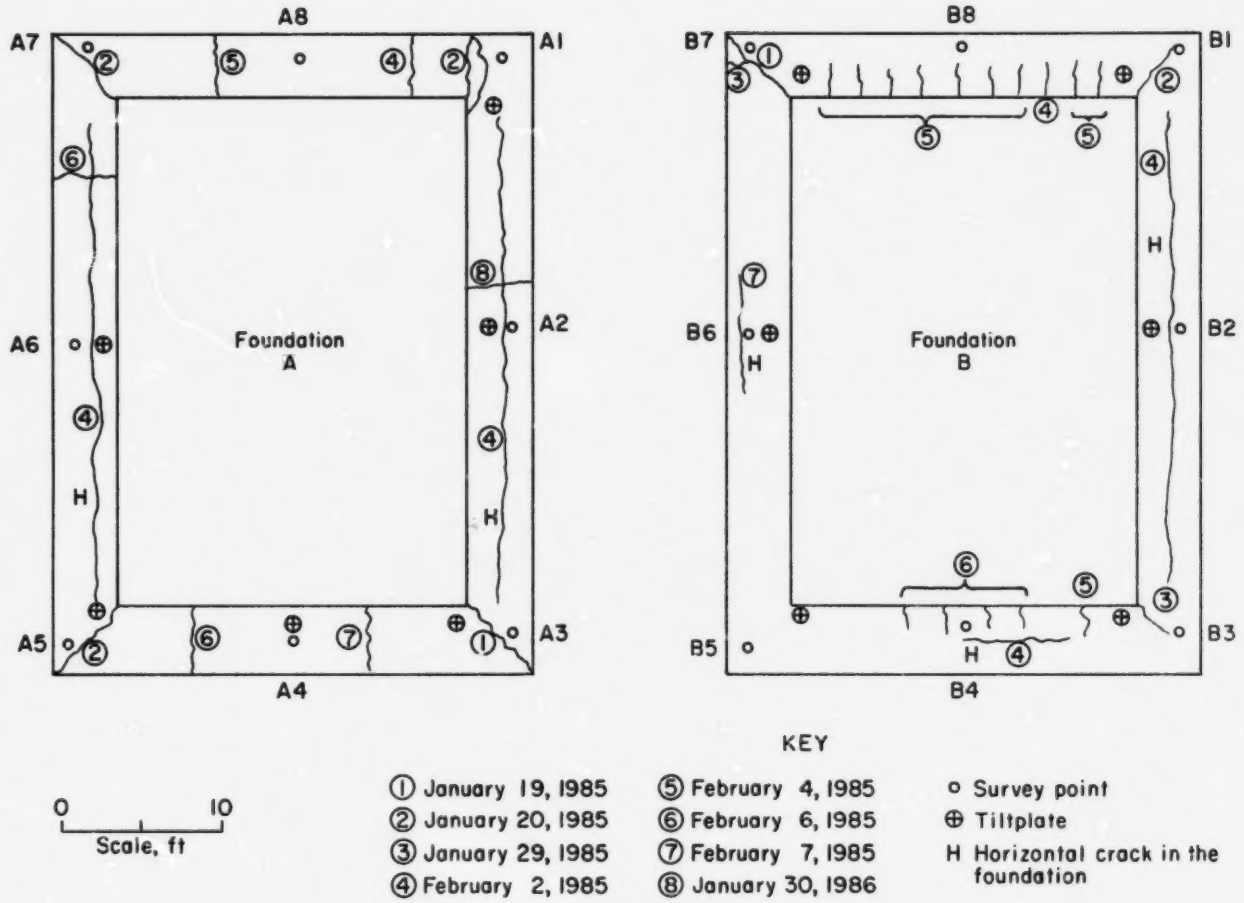


**FIGURE 24.–Foundation crack locations and dates first observed. All cracks are in footing unless labeled.**

developed on the south footing. The next day a horizontal hairline crack developed in the mortar joint on the west wall. By this time the cracks in the northeast and northwest footing corners had widened sufficiently to cause cracking and slight rotation in the north foundation block wall.

In September 1985, the panel immediately west of the site was completed; foundation B moved horizontally westward and was also displaced vertically. All of the hairline cracks in the footing observed during January and February closed; since that time, no additional cracking has been observed.

## DISCUSSION OF RESULTS

Vertical and horizontal displacements of the ground surface and the foundations followed the mining sequence. Reactions to mining the panel directly beneath and immediately to the west of the foundations were generally those that were expected given the position of the foundations relative to the geometry of the mined-out area. Because the panel immediately to the east had already been mined, ground surface displacements approached the foundations from the northeast. In addition, as the working face advanced towards the foundations, its orientation changed from N 30° E to about due north. By February 1, 1985, when the panel was completed, the foundations were actually situated in the corner of a mined-out area (fig. 26).

BEST COPY AVAILABLE



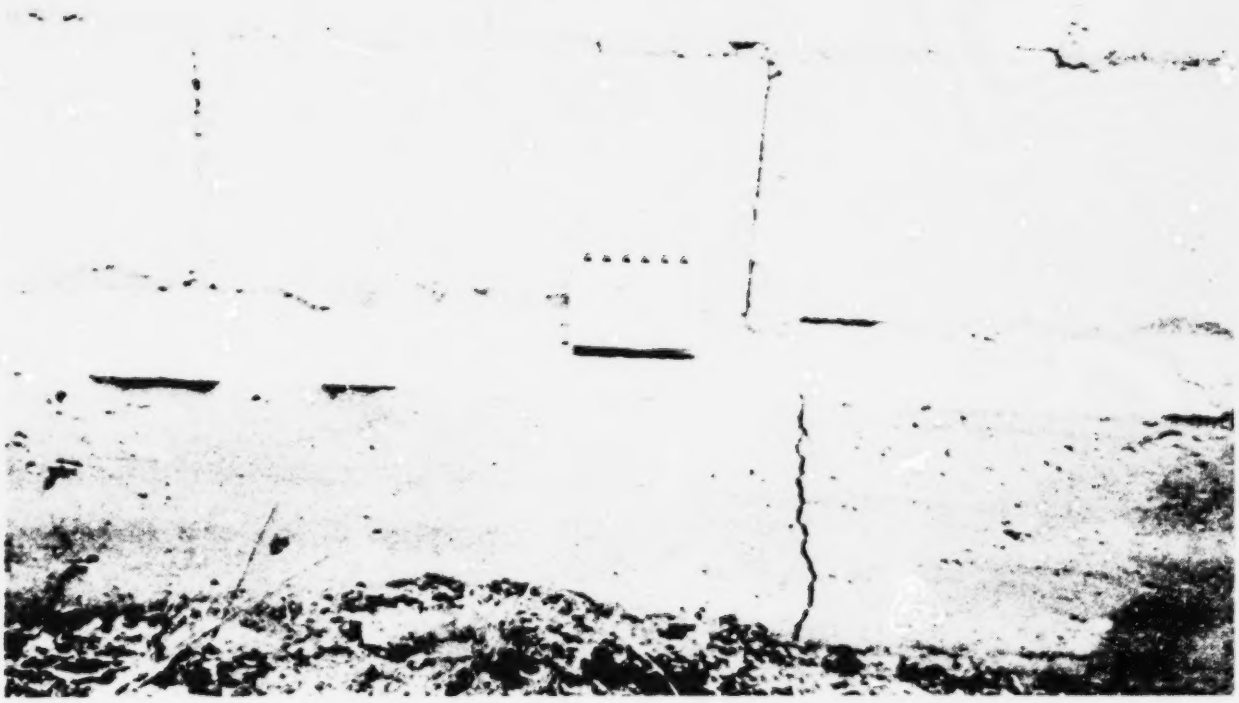

**FIGURE 25.–Crack (0.06-in wide) in south footing of foundation A located 7.5-ft west of A3.**

Foundation response to its position relative to mined-out areas is shown in figure 27 where vertical displacements are contoured through the foundations for selected times between January 15 and November 17, 1985. Initially, vertical displacements were more uniformly distributed within foundation B than within foundation A. This uneven distribution of movement may have contributed to the more severe cracking in A; the reinforcement in B helped it to react more uniformly. Both foundations were experiencing torsion. By January 19, when the first cracks appeared, B was experiencing more torsional movements than A and the increased strength of B resulted in less damage.

The panel was completed by February 1, and the vertical displacement contours show the direction from which the ground movements approached as being from about N 25° E. By May 31, the contours had rotated about 10° towards north. In July ground movements from the adjacent panel to the west began to influence the foundations, especially the west side of foundation A. The vertical displacements in foundation B showed a uniform tilt towards north. By November, several months after the western panel was completed, both foundations were uniformly tilting northward.

The mining sequence and position relative to the end of the panel also influenced how various points responded. Profiles AA' and BB' in figure 28 show that points north of the foundations did not move appreciably between April 1985 and October 1986. However, additional movements did occur close to the foundations near the end of the panel along profile BB'. The mining of the adjacent panel to the west caused more additional movement at the end of the southern panel because it caused some closure of the mine void adjacent to the barrier pillar. Points located further north had already subsided close to their maximum possible amounts and thus, were not as greatly affected by additional influences from the mining to the west.

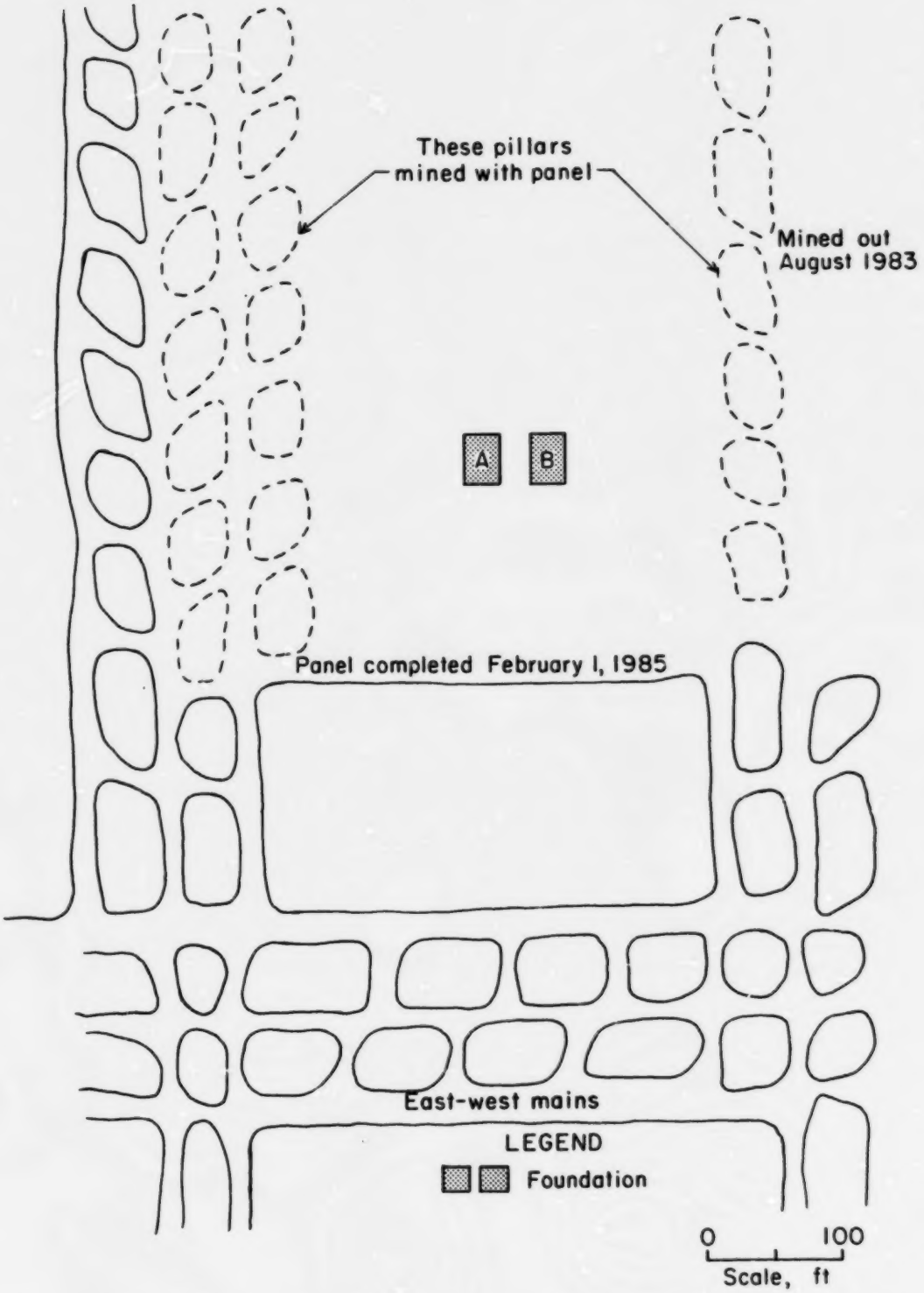


**FIGURE 26.–Position of foundations relative to mined-out area on completion of panel.**

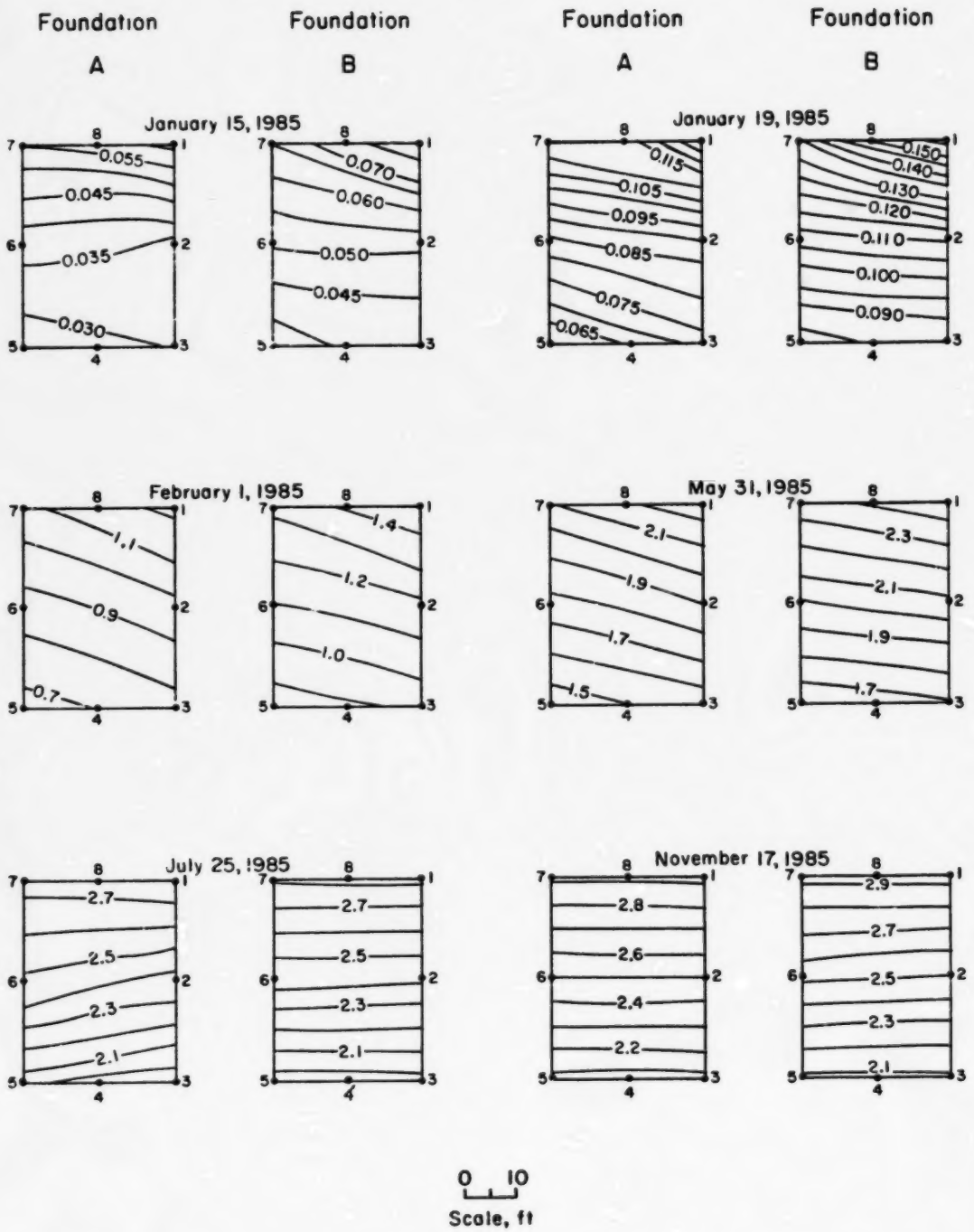


**FIGURE 27.–Vertical displacement contours through foundations. (Displacement is in feet.)**

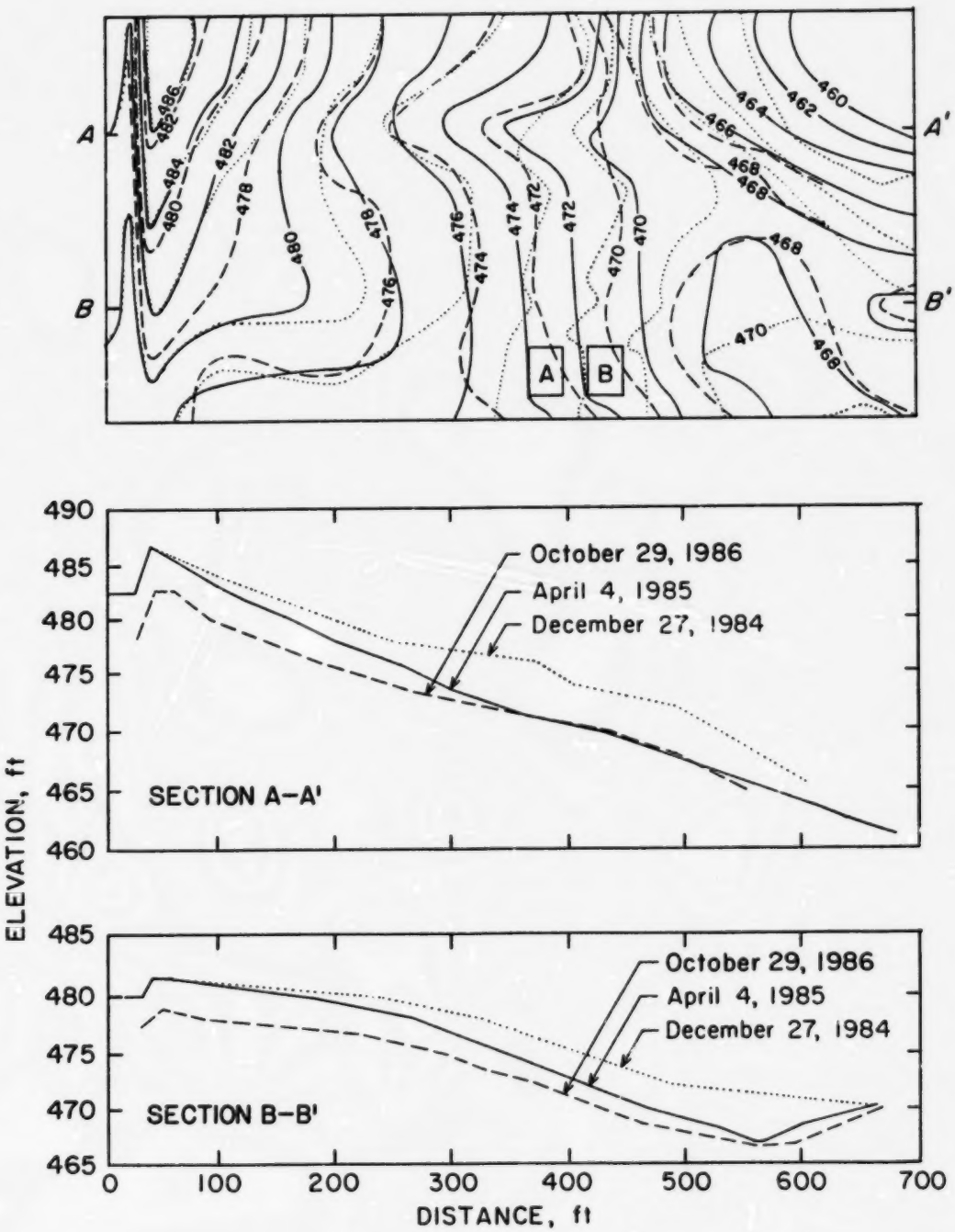


**FIGURE 28.–Site topographic map and section profiles.**

Figure 29 shows subsidence development curves for four points along the centerline of the panel. As expected, increased distance from the panel end allowed more subsidence to occur, as shown by the difference in subsidence between monument L (130 ft from panel end) and monument K (460 ft from panel end). Foundation survey points B4 and B8 are situated 150 and 190 ft, respectively, from the end of the panel. The only difference in the subsidence development curves between corresponding points on foundations A and B is that foundation B subsided slightly more than foundation A. However, once the adjacent western panel was completed, residual movements become almost identical.

Several interesting features can be pointed out on these subsidence development curves. From January 31 (day 55) onward, all four curves are remarkably similar. In fact, points L, B4, and B8 are almost identical in their appearance except for amount of subsidence. These three points show an increase in the average rate of displacement as the distance from the panel end increases. During this time L moved 0.016 ft/d, B4 moved 0.015 ft/d, and B8 moved 0.026 ft/d.

All four points showed a decrease in displacement rate as January 31 (day 55) approached. This was caused by the mine face being idled for about 10 days prior to the mining of the last 100 ft of the panel. All four points show a large increase in displacement on January 31 (day 55) and February 1 (day 56). Again, the amount of movement during these 2 days was a function of distance from the panel end. Surprisingly, monument K responded

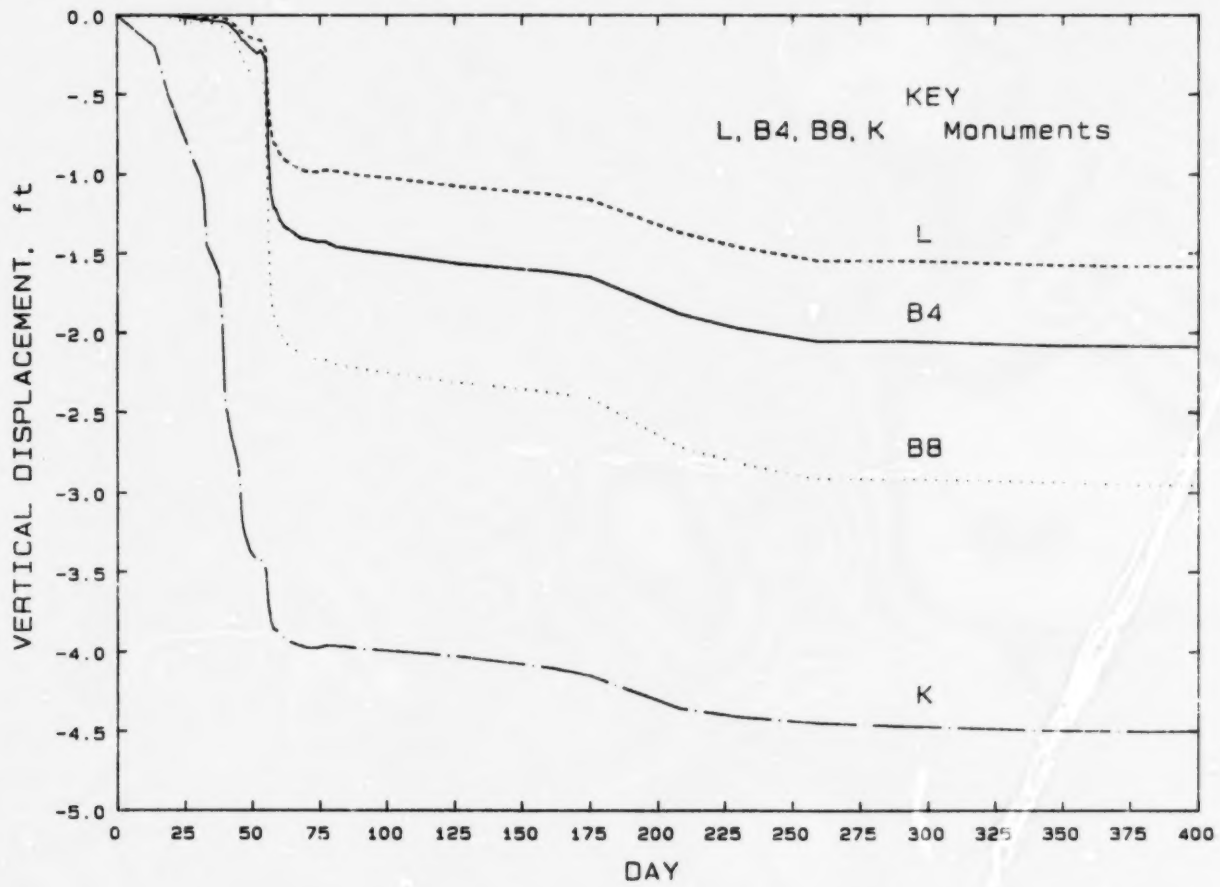


**FIGURE 29.–Subsidence development curves for four points along panel centerline.**

as well, even though it is 460 ft away. It may have responded to the removal of the block of chain pillars in the southwest corner of the panel. These were mined on February 1 (day 56) as the panel was completed.

Foundation response to vertical displacements, as shown by the tiltmeter, was also recorded. The relationship between subsidence and tilt is mathematical. The tilt at any point along the profile is the change in subsidence over a horizontal distance (16). Figure 30 shows the tilt and subsidence curve expected for a general profile. Tilt increases with subsidence until the inflection point is reached and then it decreases as subsidence continues to increase. Rank correlation tests between tilt and vertical displacement for all 12 tiltplates yielded significant correlations, with $R^2$ ranging from 0.977 to 0.994 (19). Figure 31 shows tilt plotted against subsidence for all the tiltplates located on foundations A and B. As shown, the tiltmeter can measure tilt associated with subsidence from high-extraction mining. The curves follow those expected for a general profile considering that the foundations have only experienced tension. The relationship between tilt and subsidence is different for each point because the foundations subsided differentially, thus causing different tilts at different points.

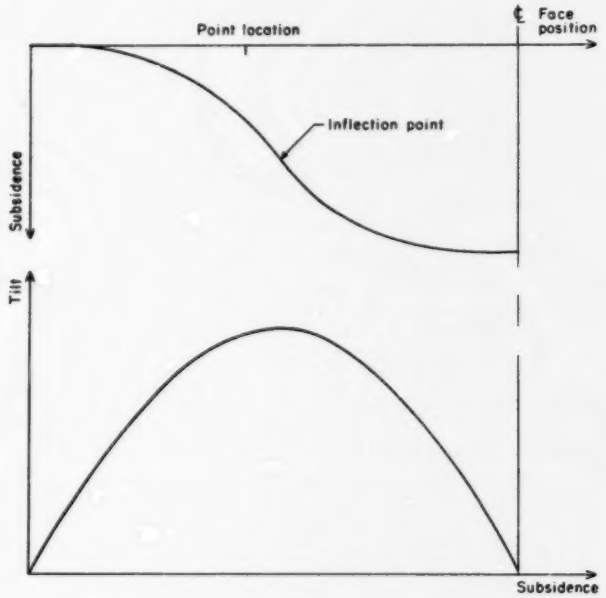


**FIGURE 30.–General plot of tilt versus subsidence.**

The tiltmeter also showed the foundations response to ground movements through changes in tilt with time. Figure 32 shows changes in tilt with time for tiltplate A6 and B6 located at the midpoint of the west wall of both foundations. Two facts need to be pointed out. First, the two peaks in change of tilt correspond to February 1 (day 56), when the panel beneath the foundations, and July 3 (day 208), when the panel to the west, most affected the structures. The response of the foundations was greater for the panel beneath than for the subjacent panel. Second, more erratic changes in tilt occurred in foundation A than in foundation B, especially as related to residual subsidence after all mining influence had ceased. The lack of tilt fluctuations in foundation B are attributed to its ability to act as an integrated unit because of its reinforced construction, whereas foundation A moved as several separate pieces after it cracked.

This difference in reaction to ground movements is also clearly shown in figure 33, where tilt direction is plotted against time for foundation A. Starting March 21, 1985 (day 104), the tiltplates on foundation A showed three distinct directions of movement: A1 and A2, N 10° W; A3 and A4, N 1° W; and A5 and A6, N 20° E. As previously stated, foundation A was cracked into at least 10 segments with the major cracks showing the most separation appearing at the corners. Figure 24 shows that the tiltplates are paired on three major foundation segments bounded by corner cracks. Not only is this pairing evident in tilt direction, it is also evident in the

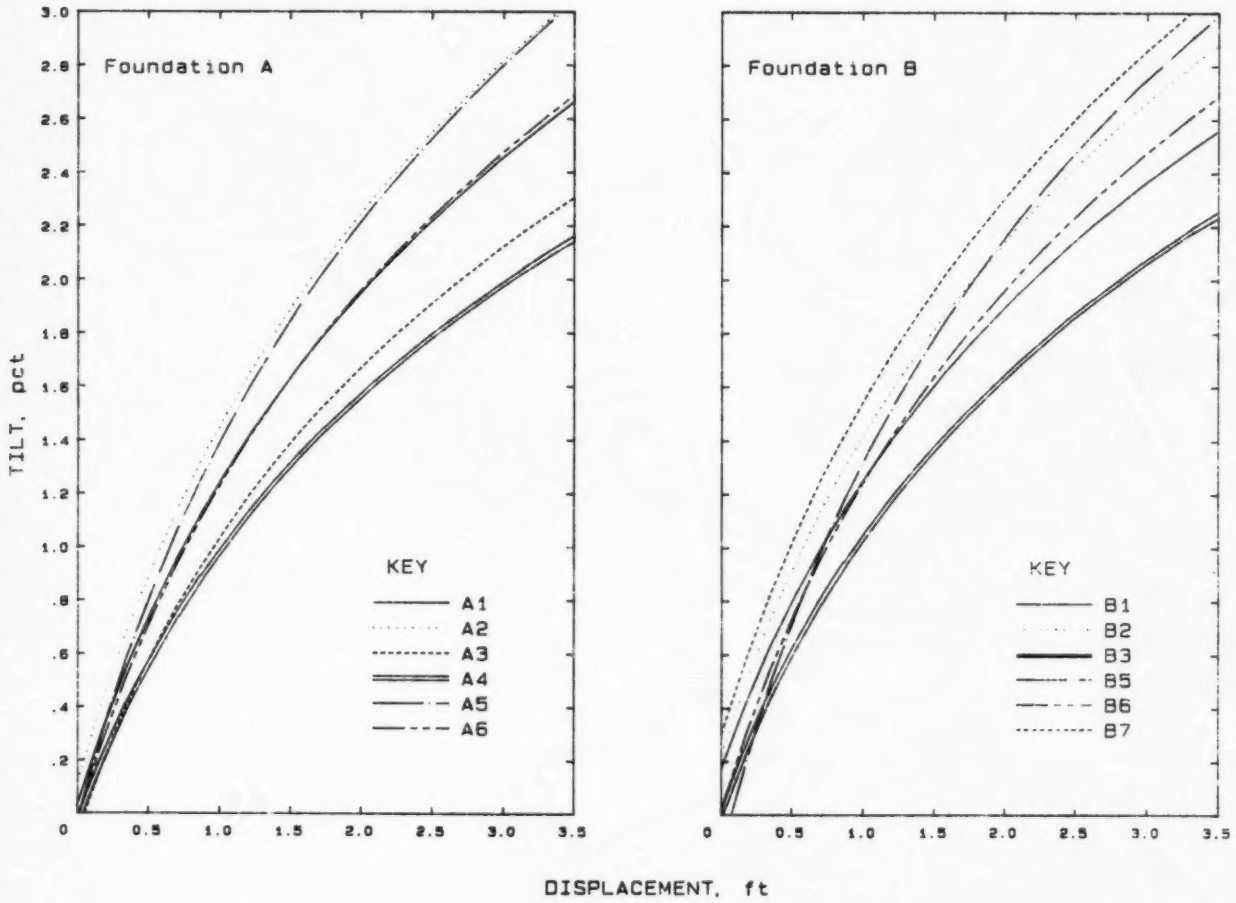


**FIGURE 31.–Tilt versus displacement curves for foundations A and B.**

amount of tilt (fig. 20). The east wall of foundation A tilted the most and towards the northeast. The south wall tilted the least and towards the north. The west wall tilted slightly less than the east wall, but tilted northwest. Thus, these three monitored wall segments moved independently in response to ground movements.

In contrast, modified foundation B responded more uniformly and as a unit. Foundation B exhibited only hairline cracks throughout. Major cracks appeared at corners B1, B3, and B7, but did not separate or rotate. All tiltplates on foundation B responded together and are now essentially tilting to the north (fig. 34). The major exception is B2, which is tilting N 18° E. The different tilt direction on the east wall is attributed to torsion and will be explained later. There is a similar uniformity in the amount of tilt (fig. 21), with the exception of the northwest corner (B7) which continued to tilt when all other tiltplates slowed after the panel was complete. The erratic shifts in tilt for B3 beginning in November 1985 (day 345) was caused by the removal of the simulated structural load on the south wall when the soil-filled bins fell off.

BEST COPY AVAILABLE

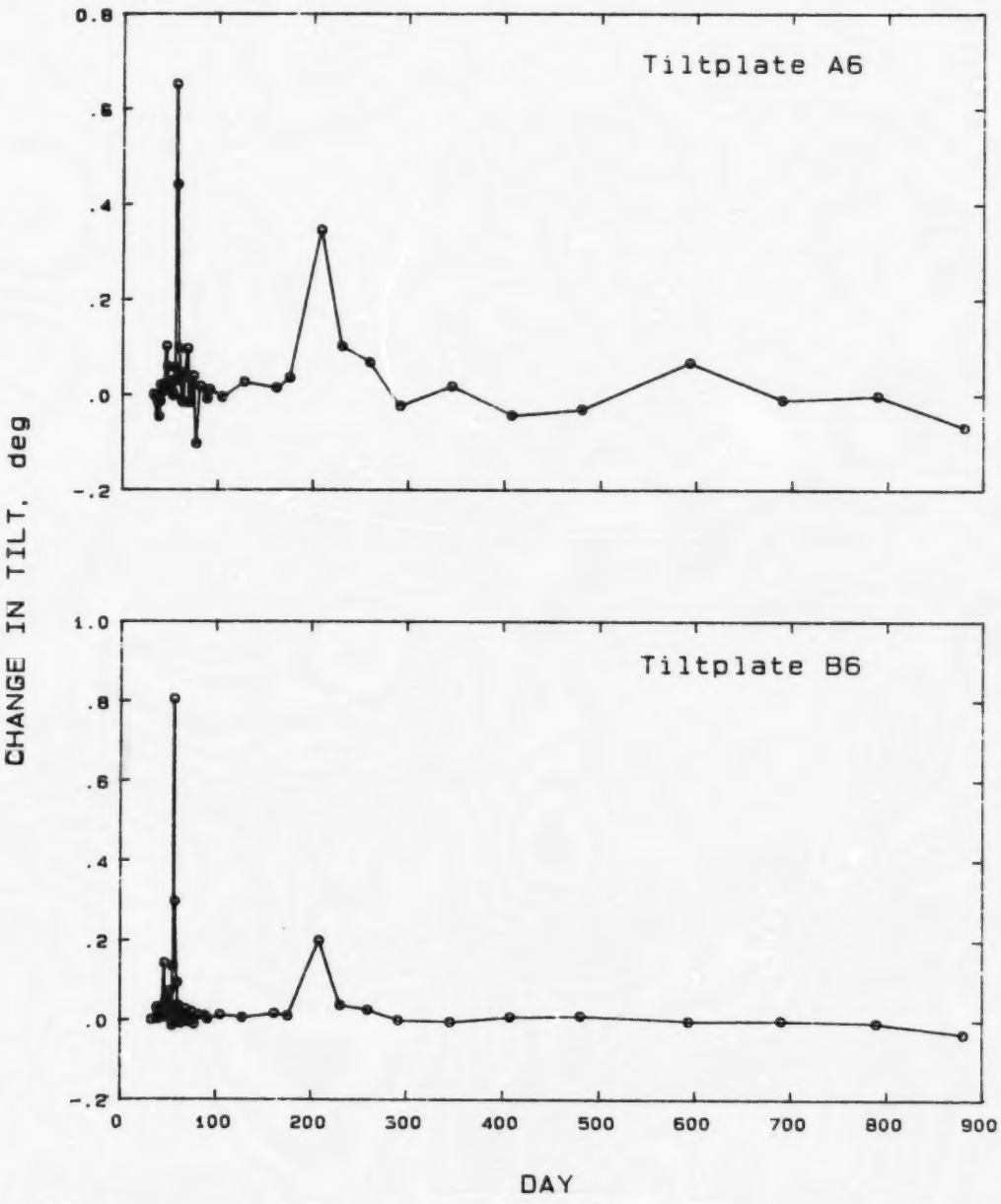


**FIGURE 32.–Change in tilt over time for center of west wall of ordinary foundation A (A6) and modified foundation B (B6).**

BEST COPY AVAILABLE



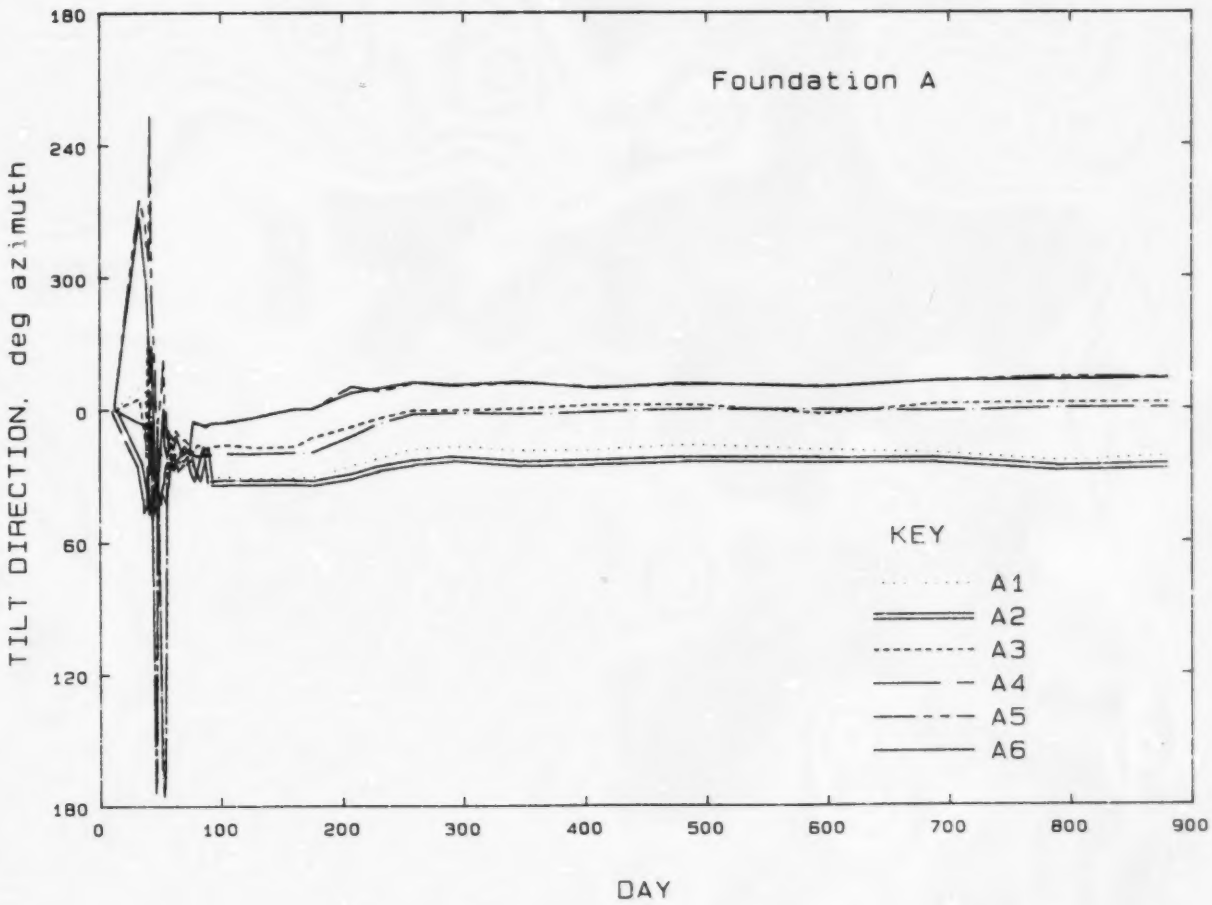


**FIGURE 33.–Changes in tilt direction for ordinary foundation A.**

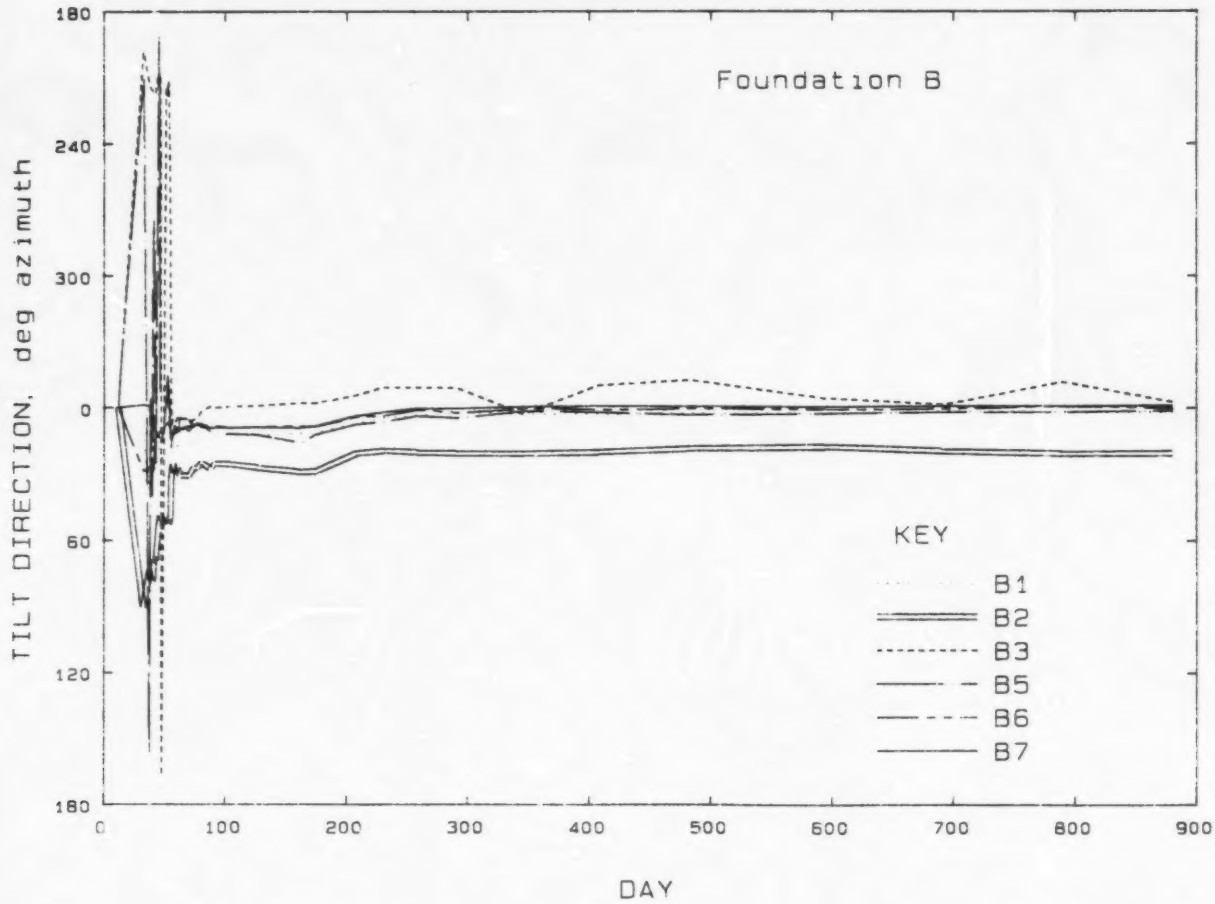


**FIGURE 34.–Changes in tilt direction for modified foundation B.**

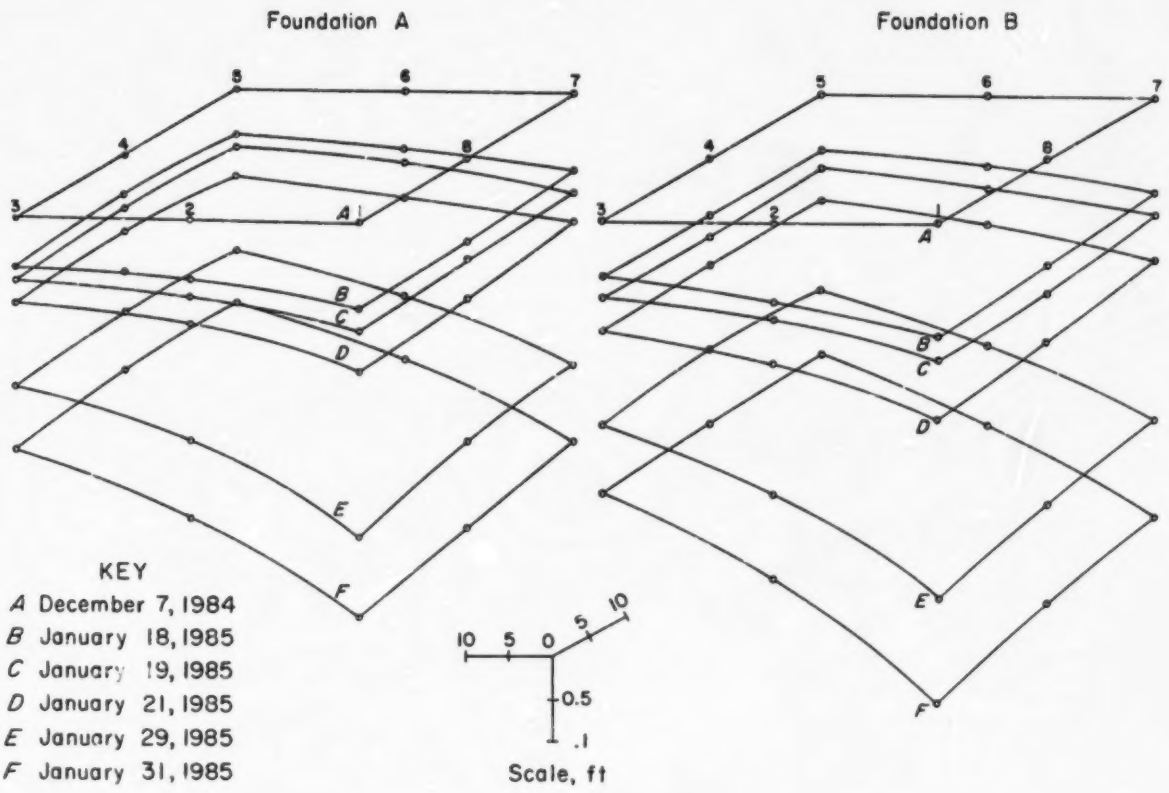


**FIGURE 35.–Development of curvature on foundations as they were undermined. The foundations cracked on January 19, 1985 (*C*).**

Measurement of tilt through time shows that both foundations went through differential tilt, which, by definition, imparts curvature; both foundations experienced curvature throughout the monitoring period (fig. 35). This curvature, along with differential horizontal movements, accounts for the failure of the foundations. Curvature also explains the apparent anomalous decreases in length on the footings between monitoring points. Table 2 gives the change in horizontal length for various periods of time on the footings. Increases in length can be attributed to extension and the development of cracks. However, the only way to explain up to 0.16 ft of decrease in length is through bending and torsion, because it is unlikely that the concrete footing could compress enough to account for this decrease in length.

TABLE 2. - Change in length between monitoring points on foundations, feet

| Location | Original length | Change | | | | | |
|---|---|---|---|---|---|---|---|
| | | 11/84-2/85 | 11/84-7/85 | 2/85-7/85 | 2/85-10/86 | 7/85-10/86 | 11/84-10/86 |
| Foundation A: | | | | | | | |
| $A_1$-$A_2$ | 19.6837 | -0.0538 | -0.0347 | +0.0191 | +0.0091 | -0.0100 | -0.0447 |
| $A_2$-$A_3$ | 18.5903 | +.0643 | -.0353 | -0.996 | -.1193 | -0.197 | -.0550 |
| $A_3$-$A_4$ | 14.5925 | -.0699 | -.0002 | +.0697 | -.0512 | -.1209 | -.1211 |
| $A_4$-$A_5$ | 13.6712 | +.0801 | -.0305 | -.1106 | +.1105 | +.1105 | +.0800 |
| $A_5$-$A_6$ | 18.3824 | +.0129 | -.0155 | -.0284 | +.0021 | +.0305 | +.0150 |
| $A_6$-$A_7$ | 20.0318 | -.0258 | +.0349 | +.0607 | +.0708 | +.0101 | +.0450 |
| $A_7$-$A_8$ | 14.9039 | +.0510 | +.0520 | +.0010 | +.0007 | -.0003 | +.0517 |
| $A_8$-$A_1$ | 13.2824 | +.0093 | -.0407 | -.0500 | -.0989 | -.0889 | -.0896 |
| Foundation B: | | | | | | | |
| $B_1$-$B_2$ | 19.6335 | -.0254 | +.0649 | +.0903 | +.0502 | -.0401 | +.0248 |
| $B_2$-$B_3$ | 18.7618 | +.1464 | -.0024 | -.1488 | -.1689 | -.0201 | -.0225 |
| $B_3$-$B_4$ | 14.9328 | -.1590 | -.0004 | +.1586 | +.0181 | -.1405 | -.1409 |
| $B_4$-$B_5$ | 13.5715 | +.0103 | -.0602 | -.0705 | -.0306 | +.0399 | -.0203 |
| $B_5$-$B_6$ | 19.6149 | -.0375 | -.0563 | -.0188 | +.0528 | +.0716 | +.0153 |
| $B_6$-$B_7$ | 18.8829 | -.0052 | -.0057 | -.0005 | -.0898 | -.0893 | -.0950 |
| $B_7$-$B_8$ | 14.7860 | -.0084 | +.0908 | +.0992 | -.0119 | -.1111 | -.0203 |
| $B_8$-$B_1$ | 13.5811 | +.0091 | -.0311 | -.0402 | -.0431 | -.0029 | -.0340 |

## SUMMARY AND CONCLUSIONS

The Bureau of Mines built, instrumented, and monitored two foundations in southern Illinois to study their response to ground movements induced by subsidence from high-extraction mining. In addition to monitoring foundation response, the capability of the instrumentation and monitoring program to detect and track foundation and ground movements was also evaluated. The study also provided data to the structural engineering profession for developing mitigative techniques to reduce damage and formulate economic repair strategies.

The study site was located over a high-extraction retreat room-and-pillar mine in southern Illinois. Between 7.5 and 8 ft of the Herrin (No. 6) coal was mined at a depth of about 720 ft. The panel mined beneath the foundations was 3,200 ft long and 300 ft wide. Approximately 85 pct of the coal was removed. The stumps and fenders that could not be safely recovered crush out immediately. No permanent pillars were left for support between panels.

Two 30- by 40-ft foundations were constructed along the centerline of the panel. Foundation A was built utilizing common construction practices for the area. The foundation consisted of an unreinforced poured concrete strip footing 16 in wide and 10 in thick. Three courses of 8-in concrete block were

placed on the footing. Foundation B was identical in dimensions, but the footing was placed on 6 in of mechanically compacted clean sand overlain by polyethylene sheeting and reinforced with eight No. 4 reinforcement bars. A trench around foundation B was filled with compressible material. Both foundations received sill plates and joists to provide a platform for loading the foundations to simulate a one-story, wood-framed structure and contents. The foundations and ground surface were monitored for 3 yr while the site was influenced by mining. Vertical and horizontal displacements and tilt were obtained during the monitoring period.

Vertical displacement was detected on the foundations when mining was 400 to 450 ft away. The foundations cracked with 0.066 ft of differential movement on foundation A and 0.076 ft on foundation B when the face was 100 ft away. Rates of vertical displacement depended on position of the mining face and the rate of mining. The greatest amount of vertical displacement measured in a 24-h period was 0.941 ft. Residual subsidence rates of 0.0003 ft/d have occurred during the last 18 months. The foundations generally followed the ground surface at slow rates of displacement, but lagged when vertical displacements occurred rapidly, as when the last 200 ft of the panel was mined. Maximum vertical displacement measured at the site was 4.58 ft. The foundations are permanently tilted with a maximum of 10.6 in of differential vertical displacement.

Horizontal movement was recorded three times during the monitoring period. Generally, horizontal movement of the ground surface was towards the centerline of the panel being mined. The further away a monument was located from the end of the panel, the more northeastward the component of movement. This reflects the position of the site on the subsidence trough in the corner of the mined-out area. The mining of the adjacent panel to the west caused subsequent horizontal movements toward the northwest.

Magnitude of horizontal displacement is a function of distance from mining, decreasing as distance increases. Maximum horizontal displacement of the ground surface in response to mining the panel beneath the site was 0.47 ft. Maximum for all mining influences was 0.88 ft. In contrast, the foundations moved a maximum of 0.58 ft horizontally from mining the panel beneath them and moved 0.73 ft from all mining. In general, horizontal movement on the foundations was differentially to the north, initially to the northeast, then rotating to the northwest as the west panel was mined. This caused the foundations to distort from their original rectangular shape.

Tilt magnitude and direction, measured on the top surface of the footings, slowly increased as the mining face approached. Significant correlations between tilt and vertical displacement were found, with $R^2$ ranging from 0.977 to 0.994. The foundations slowly tilted towards the northeast and cracked with differential tilts of 0.055 to 0.422 pct. As mining progressed beneath the foundations and to the end of the panel, tilts increased as much as 0.74 pct in a single day. Mining of the adjacent panel to the west caused an increase in tilt magnitude and a shift in tilt direction towards the north. Foundation A, closest to the western panel, showed greater changes in tilt magnitude and direction than foundation B, further to the east. The integrity of modified foundation B with its reinforced footing was shown by the uniform response of its six tiltplates.

In contrast, tilt of unmodified foundation A shows that its tiltplates moved in pairs according to their position on major footing segments bounded by major corner cracks. This pairing is evident on graphs of both tilt magnitude and tilt direction. Erratic fluctuations in tilt during the period of residual subsidence on unmodified foundation A suggest that the footing fragments are reacting to seasonal soil volume changes and floating independently of each other. This is not shown on the reinforced footing (foundation B). Because of their position close to the end of the panel, both foundations are permanently tilted between 2.92 and 1.07 pct.

The pattern of damage that occurred to both foundations is consistent with their orientation to the mine geometry, mining sequence, and magnitude of ground surface displacements. Both foundations first cracked in the northwest and southeast corners with only a total vertical displacement of 0.13 to 0.16 ft. Differential vertical displacement was between 0.066 and 0.076 ft. As mining progressed, additional cracks appeared in the corners, than in the north and south footings. These major footing cracks, up to 0.25 in wide in the unmodified footing of foundation A, generally progressed up into the concrete block wall, either along mortar joints or directly through the blocks. In contrast, the reinforced footing of foundation B exhibited only hairline cracks along the north and south footings. Finally, horizontal cracks appeared in the mortar joints between the first and second course of concrete block in the east and west walls. In both foundations the central beam moved southward at least 1 in relative to the south wall.

The pattern of damage is consistent with what would be expected if a three-dimensional, rectangular foundation was subjected to a combination of bending and torsion. Facilitated by laboratory models of rectangular foundations, the vertical and horizontal displacements, tilt magnitudes and directions, and crack patterns as measured and observed on the foundations can be explained when the foundation is simultaneously bent and torqued (fig. 36). Bending and torquing of the foundations also explains the decrease in length between some monitoring points (table 2). This cannot be attributed to compression of the concrete footing because the foundations have not entered the compression area of the subsidence profile and it is unlikely that concrete could compress enough to account for the amount of observed shortening.

The two views in figure 36 show that the northeast corner moved more vertically than other points on the foundations. The vertical displacement data collected on both foundations confirm that initially the northeast corners moved the greatest, while the southwest

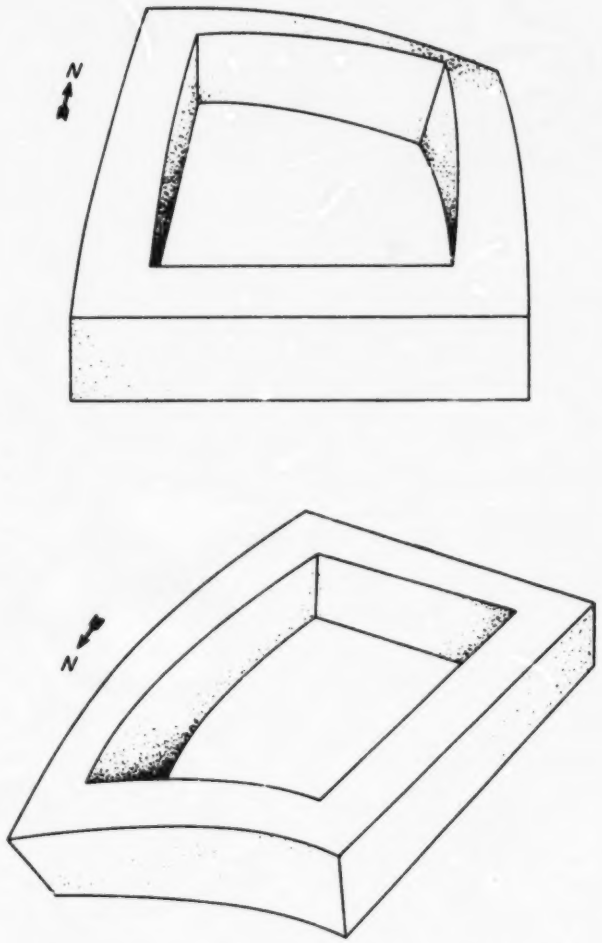


**FIGURE 36.–Three-dimensional model of rectangular foundation, based on movements observed at the site.**

corners moved the least. This is consistent with the position of the foundations relative to the panel end and west chain pillars, putting them in the corner of the evolving subsidence trough.

Horizontal displacements are also generally consistent with bending and torsion, however, the horizontal movements measured are a combination of movement caused by the developing subsidence profile and the bending and torsion of the foundations. Each foundation reacted differently to the horizontal movement. Unmodified foundation A was cracked into many segments each moving separately; modified foundation B, because of its reinforced footing, reacted as a unit. Horizontal displacements show that the

east and west walls bulged out while the north and south walls bowed inward--this is consistent with laboratory model analysis. Part of this observed movement is caused by the twisting of the walls in torsion. With the south walls bowing inward, the relative movement of the central beam is accounted for. In addition, tilt directions indicate a slight south to southwest tilt on south walls because the combination of relative horizontal movement northward and beam movement southward rotates the top of the foundation wall towards the south.

The magnitude and directions of tilts measured on the foundations are the most compelling evidence for torsion. Initial tilts on northeast corners are the greatest while southern tilts are smallest. In general, measured tilt directions are northeast for northeast corner, northeast to east for center of east wall, west to northwest for southeast corner, northward for center of south wall, erratic or stationary for the southwest corner, east to northeast for center of west wall, east to southeast for northwest corner, and northwest for center of north wall. These tilt directions reflect model tilts shown in figure 36 with the added complication of a developing progressive tilt to the north from the subsidence profile. These tilts and tilt directions are more easily seen on the modified and reinforced foundation (B) than on the unmodified foundation (A) because foundation A was broken into several segments early in the monitoring program. The eastward tilt component of the center of the east wall of foundation B best shows the effects of torsion.

The crack pattern observed in the foundations is consistent with bending and torsion. The corners were points of stress concentration and the first to respond to the ground movements; northwest and southeast corners developed cracks first in response to trough development, and northeast and southwest corners cracked in response to torsional movements. Cracks in the footings resulted from curvature developed during bending and torsion. This is most evident on the north footing of foundation B where at least 10 hairline cracks were observed. The development of these cracks is explained by the amount of curvature developed in the footing as shown in the lower view of figure 36. Less curvature was developed in the south wall, which resulted in fewer hairline cracks.

The horizontal cracks that appeared in the mortar joints along the east and west walls can be explained by modeling a wall in torsion with bending (fig. 37). Torsional movement causes shear along horizontal joints. By superimposing bending,

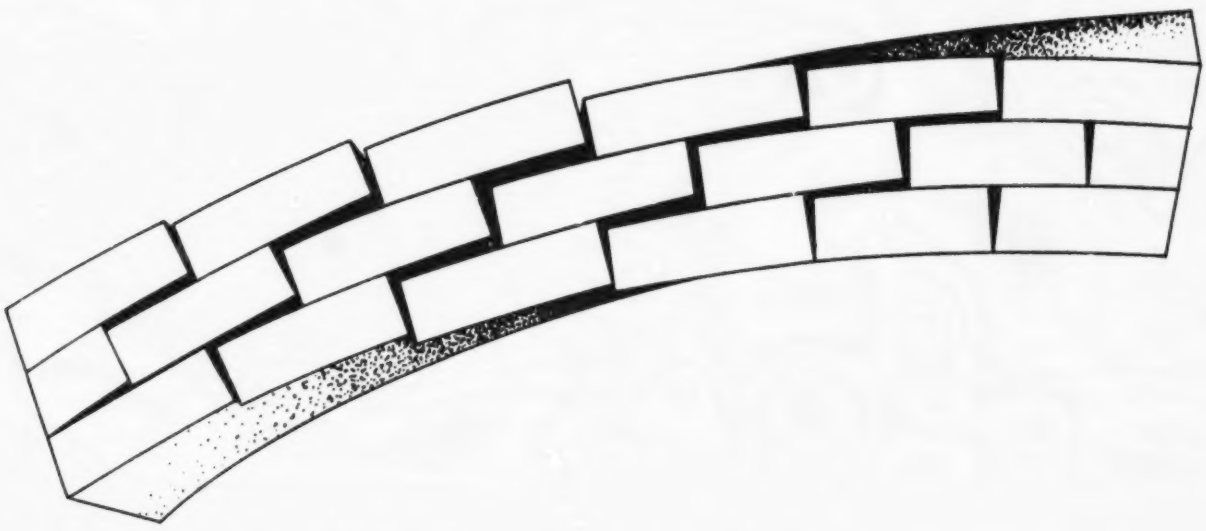

FIGURE 37.–Model of wall in torsion and bending.

these joints begin to open. The buttressing effect of the foundation corners played a key role in the development of these mortar joint cracks. It was originally assumed that these horizontal cracks were caused by compression; however, the foundations have not been placed in compression and have reached only the position of the inflection point on the subsidence profile. The short horizontal crack observed on the south wall of foundation B is attributed to the interaction of the central beam on the top of the wall pushing it southward while horizontal movements drag the footing northward. This top to bottom shear may contribute to the development of this horizontal crack.

The measured and observed deformations recorded on the two foundations indicate that they primarily failed in torsion. Measured vertical, horizontal, and differential displacements show that the foundations responded to the developing mine geometry, mining method and schedule, and to the resulting subsidence trough and accompanying ground movements. The performance of the reinforced foundation indicates that certain mitigative measures can reduce subsidence damage. The tiltmeter proved to be an excellent alternative instrument for monitoring foundation response to subsidence-induced ground movements. The data generated by this study will guide the design of future monitoring programs and will help in the design of economic subsidence mitigative and repair techniques for residential foundations.

## REFERENCES


1. Murphy, E., R. E. Yarbrough, and S. C. Bradford. A Review of Claims Data-Illinois Mine Subsidence Insurance Fund, October 1979 through October 1985. Paper in Proceedings of the 2nd Workshop on Surface Subsidence Due to Underground Mining (Morgantown, WV, June 9-11, 1986). WV Univ., Morgantown, WV, 1986, pp. 13-18.

2. Bruhn, R. W., R. C. Speck, W. S. McCann, and O. S. Cecil. Survey of Ground Surface Conditions Affecting Structural Response to Subsidence (contract J0295014, GAI Consultants, Inc.). BuMines OFR 12-84, 1983, 601 pp.; NTIS PB 84-155860.

3. Marino, G. G. Subsidence Damaged Homes Over Room-and-Pillar Mines in Illinois. Ph.D. Thesis, Univ. IL, Urbana, IL, 1985, 435 pp.

4. Grayson, R. L., and G. Mishra. Understanding and Controlling Mine Subsidence Over a Longwall Panel. Pres. at American Mining Congress Coal Convention, St. Louis, MO, May 9-12, 1982, 22 pp.; available from American Mining Congress, Washington, DC.

5. Peng, S. S., and D. Y. Geng. Surface Subsidence, Overburden Behaviour, and Structural Damages Due to Longwall Mining--Two Case Histories. Paper in 2nd International Conference on Stability in Underground Mining, ed. by A. B. Szwilski and C. O. Brawner (Lexington, KY, Aug. 6-8, 1984). Soc. Min. Eng. AIME, Littleton, CO, 1984, pp. 497-523.

6. Littlejohn, G. S. Monitoring Foundation Movements in Relation to Adjacent Ground. Ground Eng., v. 6, No. 4, 1973, pp. 17-22.

7. _____. Observation of Brick Walls Subjected to Mining Subsidence. Ch. in Settlement of Structures. Halstead Press, London, 1975, pp. 384-393.

8. Burland, J. B., and C. P. Wroth. Settlement of Buildings and Associated Damage. Sec. in Settlement of Structures. Wiley, 1974, pp. 611-654.

9. Burland, J. B., B. B. Broms, and V. F. B. deMello. Behaviour of Foundations and Structures. Paper in Proceedings, 9th International Conference on Soil Mechanics and Foundation Engineering, Tokyo, Japan, July 11, 1977. Japanese Soc. Soil Mech. and Foundation Eng., Tokyo, Japan, 1977, pp. 495-546.

10. Whittaker, B. N., and A. G. Pasamehmetoglu. Ground Tilt in Relation to Subsidence in Longwall Mining. Int. J. Rock Mech. Min. Sci. and Geomech. Abs., v. 18, No. 14, 1981, pp. 321-329.

11. National Coal Board. Subsidence Engineers' Handbook. London. 2d ed., 1975, 110 pp.

12. Brauner, G. Subsidence Due to Underground Mining--Ground Movements and Mining Damage. BuMines IC 8572, 1973, 53 pp.

13. Leighton, M. M., G. E. Ekblaw, and C. L. Horberg. Physiographic Divisions of Illinois. IL State Geol. Surv., Rep. Invest. 129, 1948, 19 pp.

14. Willmar, H. B., and J. C. Frye. Pleistocene Stratigraphy of Illinois. IL State Geol. Surv., Bull. 94, 1970, 204 pp.

15. Keys, J. N., and W. J. Nelson. The Rend Lake Fault System in Southern Illinois. IL State Geol. Surv. Circ. 513, 1980, 23 pp.

16. Flowers, A. E. Plans for Long, Productive Life. Coal Age, v. 62, No. 2, 1957, pp. 77-85.

17. Yarbrough, R. E. Monitoring of Two Foundations Subsided by a High Extraction Coal Mine, Sesser, Illinois. Paper in Proceedings, Second Conference on Ground Control Problems in the Illinois Coal Basin, ed. by Y. P. Chugh (Carbondale, IL, May 29-31, 1985). Southern IL Univ., Carbondale, IL, 1985, pp. 151-158.

18. Triplett, T. L., R. E. Yarbrough, and L. R. Powell. Foundation Response to Subsidence Induced by High Extraction Mining in Southern Illinois. Paper in Rock Mechanics: Key to Energy Production, ed. by H. L. Hartman (Proc. 27th U.S. Symp. Rock Mech., Tuscaloosa, AL, June 23-25, 1986). Soc. Min. Eng. AIME, Littleton, CO, 1986, pp. 283-290.

19. Powell, L. R., T. L. Triplett, R. E. Yarbrough. Measurement and Analysis of Foundation Tilt Resulting from Mine Subsidence in Southern Illinois. Paper in the Proceedings of the 2nd Workshop on Surface Subsidence Due to Underground Mining (Morgantown, WV, June 9-11, 1986). WV Univ., Morgantown, WV, 1986, pp. 142-152.

20. Yarbrough, R. E. Digitilt Tiltmeter System Utilized to Monitor Structural Response to Ground Movements Induced by Coal Mine Subsidence. The Indicator, v. 15, No. 1, 1986, pp. 6-7.

## APPENDIX A.--VERTICAL DISPLACEMENTS

TABLE 1. - Elevations and vertical displacements of ground surface, feet

| | Monument A | | Monument B | | Monument C | | Monument D | | Monument L | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Elev | Change | Elev | Change | Elev | Change | Elev | Change | Elev | Change |
| 07-DEC-84 | 474.0400 | 0.0000 | 473.9600 | 0.0000 | 478.6400 | 0.0000 | 479.8200 | 0.0000 | 474.5600 | 0.0000 |
| 19-DEC-84 | 474.0400 | .0000 | 473.9622 | .0022 | 478.6440 | .0040 | 479.8308 | .0108 | | |
| 26-DEC-84 | | | | | | | 479.8308 | .0108 | 474.5576 | -.0024 |
| 04-JAN-85 | | | | | | | 479.8200 | .0000 | | |
| 07-JAN-85 | | | | | 478.6400 | .0000 | 479.8200 | .0000 | | |
| 08-JAN-85 | | | | | 478.6400 | .0000 | 479.8200 | .0000 | 474.5400 | -.0200 |
| 09-JAN-85 | | | | | 478.6400 | .0000 | 479.8300 | .0100 | 474.5400 | -.0200 |
| 14-JAN-85 | 474.0400 | .0000 | 473.9632 | .0032 | 478.6438 | .0038 | 479.8261 | .0061 | 474.5472 | -.0128 |
| 15-JAN-85 | 474.0400 | .0000 | 473.9603 | .0003 | 478.6410 | .0010 | 479.8230 | .0030 | 474.5386 | -.0214 |
| 16-JAN-85 | | | | | 478.6410 | .0010 | 479.8197 | -.0003 | 474.5360 | -.0240 |
| 17-JAN-85 | | | | | 478.6410 | .0010 | 479.8206 | .0006 | 474.5292 | -.0308 |
| 18-JAN-85 | | | | | 478.6410 | .0010 | 479.8204 | .0004 | 474.5225 | -.0375 |
| 19-JAN-85 | | | | | 478.6410 | .0010 | 479.8181 | -.0019 | 474.5084 | -.0516 |
| 21-JAN-85 | 474.0400 | .0000 | 473.9445 | -.0155 | 478.6206 | -.0194 | 479.7960 | -.0240 | 474.4738 | -.0862 |
| 22-JAN-85 | 474.0400 | .0000 | 473.9413 | -.0187 | 478.6137 | -.0263 | 479.7876 | -.0324 | 474.4488 | -.1112 |
| 23-JAN-85 | 474.0400 | .0000 | 473.9356 | -.0244 | 478.6093 | -.0307 | 479.7976 | -.0224 | 474.4451 | -.1149 |
| 24-JAN-85 | 474.0400 | .0000 | 473.9353 | -.0247 | 478.6117 | -.0283 | 479.7866 | -.0334 | 474.4287 | -.1313 |
| 25-JAN-85 | 474.0400 | .0000 | 473.9350 | -.0250 | 478.6110 | -.0290 | 479.7848 | -.0352 | 474.4214 | -.1386 |
| 28-JAN-85 | 474.0400 | .0000 | 473.9327 | -.0273 | 478.6067 | -.0333 | 479.7806 | -.0394 | 474.4009 | -.1591 |
| 29-JAN-85 | 474.0040 | .0000 | 473.9312 | -.0288 | 478.6123 | -.0277 | 479.7840 | -.0360 | 474.4007 | -.1593 |
| 30-JAN-85 | 474.0400 | .0000 | 473.9306 | -.0294 | 478.6041 | -.0359 | 479.7755 | -.0445 | 474.3766 | -.1834 |
| 31-JAN-85 | 474.0400 | .0000 | 473.9340 | -.0260 | 478.6052 | -.0348 | 479.7713 | -.0487 | 474.3396 | -.2204 |
| 01-FEB-85 | 474.0400 | .0000 | 473.9332 | -.0268 | 478.6049 | -.0351 | 479.7694 | -.0506 | 473.9796 | -.5804 |
| 02-FEB-85 | 474.0476 | .0076 | 473.9332 | -.0268 | 478.5992 | -.0408 | 479.7604 | -.0596 | 473.8212 | -.7388 |
| 03-FEB-85 | 474.0400 | .0000 | 473.9288 | -.0312 | 478.5931 | -.0469 | 479.7530 | -.0670 | 473.7522 | -.8078 |
| 04-FEB-85 | 474.0400 | .0000 | 473.9191 | -.0409 | 478.5890 | -.0510 | 479.7498 | -.0702 | 473.7382 | -.8218 |
| 05-FEB-85 | 474.0400 | .0000 | 473.9162 | -.0438 | 478.5867 | -.0533 | 479.7449 | -.0751 | 473.6869 | -.8731 |
| 06-FEB-85 | 474.0400 | .0000 | 473.9123 | -.0477 | 478.5836 | -.0564 | 479.7438 | -.0762 | 473.6711 | -.8889 |
| 07-FEB-85 | 474.0400 | .0000 | 473.9088 | -.0512 | 478.5775 | -.0625 | 479.7365 | -.0835 | 473.6477 | -.9123 |
| 08-FEB-85 | 474.0400 | .0000 | 473.9061 | -.0539 | 478.5767 | -.0633 | 479.7347 | -.0853 | 473.6339 | -.9261 |
| 13-FEB-85 | 474.0400 | .0000 | 473.9027 | -.0573 | 478.5713 | -.0687 | 479.7295 | -.0905 | 473.5883 | -.9717 |
| 15-FEB-85 | 474.0400 | .0000 | 473.9051 | -.0549 | 478.5719 | -.0681 | 479.7292 | -.0908 | 473.5779 | -.9821 |
| 19-FEB-85 | 474.0400 | .0000 | 473.8879 | -.0721 | 478.5832 | -.0568 | 479.7404 | -.0796 | 473.5700 | -.9900 |
| 22-FEB-85 | 474.0356 | -.0044 | 473.9197 | -.0403 | 478.6158 | -.0242 | 479.7722 | -.0478 | 473.5891 | -.9709 |
| 26-FEB-85 | 474.0314 | -.0086 | 473.9203 | -.0397 | 478.6192 | -.0208 | 479.7717 | -.0483 | 473.5758 | -.9842 |
| 08-MAR-85 | 474.0345 | -.0055 | 473.9219 | -.0381 | 478.6214 | -.0186 | 479.7720 | -.0480 | 473.5514 | -1.0086 |
| 21-MAR-85 | 474.0316 | -.0084 | 473.9186 | -.0414 | 478.6176 | -.0224 | 479.7664 | -.0536 | 473.5260 | -1.0340 |
| 13-APR-85 | 474.0292 | -.0108 | 473.9164 | -.0436 | 478.6127 | -.0273 | 479.7571 | -.0629 | 473.4769 | -1.0831 |
| 17-MAY-85 | 474.0258 | -.0142 | 473.9074 | -.0526 | 478.6006 | -.0394 | 497.7397 | -.0803 | 473.4293 | -1.1307 |
| 31-MAY-85 | 474.0245 | -.0155 | 473.9063 | -.0537 | 478.5991 | -.0409 | 479.7357 | -.0843 | 473.3996 | -1.1604 |
| 03-JUL-85 | 474.0237 | -.0163 | 473.9020 | -.0580 | 478.5918 | -.0482 | 479.6839 | -.1361 | 473.1916 | -1.3684 |
| 25-JUL-85 | 474.0257 | -.0143 | 473.9030 | -.0570 | 478.5890 | -.0510 | 479.5956 | -.2244 | 473.1022 | -1.4578 |
| 23-AUG-85 | 474.0302 | -.0098 | 473.9064 | -.0536 | 478.5802 | -.0598 | 478.8116 | -1.0084 | 473.0147 | -1.5453 |
| 24-SEP-85 | 474.0283 | -.0117 | 473.9038 | -.0562 | 478.5727 | -.0673 | 478.7633 | -1.0567 | 473.0114 | -1.5486 |
| 17-NOV-85 | 474.0265 | -.0135 | 473.9058 | -.0542 | 478.5693 | -.0707 | 478.7262 | -1.0938 | 472.9858 | -1.5742 |
| 19-DEC-85 | 474.0280 | -.0120 | 473.9069 | -.0531 | 478.5708 | -.0692 | 478.7017 | -1.1183 | 472.9774 | -1.5826 |
| 18-JAN-86 | 474.0296 | -.0104 | 473.9067 | -.0533 | 478.5692 | -.0708 | 478.6723 | -1.1477 | 472.9685 | -1.5915 |
| 01-APR-86 | 474.0405 | .0005 | 473.9097 | -.0503 | 478.5666 | -.0734 | 478.4944 | -1.3256 | 472.9438 | -1.6162 |
| 23-JUL-86 | 474.0357 | -.0043 | 473.8353 | -.1247 | 478.5589 | -.0811 | 478.4619 | -1.3581 | 472.9336 | -1.6264 |
| 28-OCT-86 | 474.0341 | -.0059 | 473.8360 | -.1240 | 478.5566 | -.0834 | 478.4430 | -1.3770 | 472.9299 | -1.6301 |
| 06-MAY-87 | 474.0321 | -.0079 | 473.8348 | -.1252 | 478.5538 | -.0862 | 478.4278 | -1.3922 | 472.9251 | -1.6349 |

See explanatory note at end of table.

TABLE A-1. - Elevations and vertical displacements of ground surface, feet--Continued

| | Monument F | | Monument N | | Monument J | | Monument K | |
|---|---|---|---|---|---|---|---|---|
| | Elev | Change | Elev | Change | Elev | Change | Elev | Change |
| 07-DEC-84 | 474.7000 | 0.0000 | 473.1600 | 0.0000 | 475.0000 | 0.0000 | 476.9800 | 0.0000 |
| 19-DEC-84 | | | | | | | | |
| 26-DEC-84 | 474.6829 | -.0171 | 473.1383 | -.0217 | 474.9257 | -.0743 | 476.4718 | -.5082 |
| 04-JAN-85 | | | | | 474.8700 | -.1300 | 476.0700 | -.9100 |
| 07-JAN-85 | 474.6500 | -.0500 | 473.1100 | -.0500 | 474.8700 | -.1300 | 475.9600 | -1.0200 |
| 08-JAN-85 | 474.6600 | -.0400 | 473.1100 | -.0500 | 474.8700 | -.1300 | 475.8400 | -1.1400 |
| 09-JAN-85 | 474.6700 | -.0300 | 473.1200 | -.0400 | 474.8800 | -.1200 | 475.5300 | -1.4500 |
| 14-JAN-85 | 474.6591 | -.0409 | 473.1076 | -.0524 | 474.8335 | -.1665 | 475.3463 | -1.6337 |
| 15-JAN-85 | 474.6341 | -.0659 | 473.0783 | -.0817 | 474.7317 | -.2683 | 474.9754 | -2.0046 |
| 16-JAN-85 | 474.6245 | -.0755 | 473.0692 | -.0908 | 474.6106 | -.3894 | 474.5246 | -2.4554 |
| 17-JAN-85 | 474.6124 | -.0876 | 473.0557 | -.1043 | 474.5722 | -.4278 | 474.4491 | -2.5309 |
| 18-JAN-85 | 474.5919 | -.1081 | 473.0298 | -.1302 | 474.4951 | -.5049 | 474.3469 | -2.6331 |
| 19-JAN-85 | 474.5644 | -.1356 | 473.0025 | -.1575 | 474.4387 | -.5613 | 474.2834 | -2.6966 |
| 21-JAN-85 | 474.5077 | -.1923 | 472.9329 | -.2271 | 474.3014 | -.6986 | 474.1443 | -2.8357 |
| 22-JAN-85 | 474.4435 | -.2565 | 472.8367 | -.3233 | 473.8987 | -1.1013 | 473.8078 | -3.1722 |
| 23-JAN-85 | 474.4202 | -.2798 | 472.8097 | -.3503 | 473.7792 | -1.2208 | 473.7174 | -3.2626 |
| 24-JAN-85 | 474.3885 | -.3115 | 472.7760 | -.3840 | 473.7125 | -1.2875 | 473.6639 | -3.3161 |
| 25-JAN-85 | 474.3700 | -.3300 | 472.7566 | -.4034 | 473.6720 | -1.3280 | 473.6127 | -3.3673 |
| 28-JAN-85 | 474.3023 | -.3977 | 472.6877 | -.4723 | 473.5566 | -1.4434 | 473.5403 | -3.4397 |
| 29-JAN-85 | 474.3167 | -.3833 | 472.7001 | -.4599 | 473.5612 | -1.4388 | 473.5522 | -3.4278 |
| 30-JAN-85 | 474.2859 | -.4141 | 472.6692 | -.4908 | 473.5215 | -1.4785 | 473.5216 | -3.4584 |
| 31-JAN-85 | 474.2118 | -.4882 | 472.5782 | -.5818 | 473.4211 | -1.5789 | 473.4858 | -3.4942 |
| 01-FEB-85 | 473.4531 | -1.2469 | 471.6375 | -1.5225 | 472.4994 | -2.5006 | 473.2645 | -3.1755 |
| 02-FEB-85 | 473.0612 | -1.6388 | 471.2474 | -1.9126 | 472.1605 | -2.8395 | 473.1662 | -3.8138 |
| 03-FEB-85 | 472.9347 | -1.7653 | 471.1273 | -2.0327 | 472.0581 | -2.9419 | 473.1172 | -3.8628 |
| 04-FEB-85 | 472.8898 | -1.8102 | 471.0880 | -2.0720 | 472.0242 | -2.9758 | 473.1168 | -3.8632 |
| 05-FEB-85 | 472.8149 | -1.8851 | 471.0170 | -2.1430 | 471.9602 | -3.0398 | 473.0778 | -3.9022 |
| 06-FEB-85 | 472.7815 | -1.9185 | 470.9874 | -2.1726 | 471.9341 | -3.0659 | 473.0726 | -3.9074 |
| 07-FEB-85 | 472.7437 | -1.9563 | 470.9532 | -2.2068 | 471.9017 | -3.0983 | 473.0584 | -3.9216 |
| 08-FEB-85 | 472.7269 | -1.9731 | 470.9356 | -2.2244 | 471.8878 | -3.1122 | 473.0468 | -3.9332 |
| 13-FEB-85 | 472.6579 | -2.0421 | 470.8710 | -2.2890 | 471.8282 | -3.1718 | 473.0117 | -3.9683 |
| 15-FEB-85 | 472.6447 | -2.0553 | 470.8589 | -2.3011 | 471.8182 | -3.1818 | 473.0042 | -3.9758 |
| 19-FEB-85 | 472.6298 | -2.0702 | 470.8454 | -2.3146 | 471.8063 | -3.1937 | 473.0015 | -3.9785 |
| 22-FEB-85 | 472.6436 | -2.0564 | 470.8597 | -2.3003 | 471.8238 | -3.1762 | 473.0184 | -3.9616 |
| 26-FEB-85 | 472.6231 | -2.0769 | 470.8416 | -2.3184 | 471.8047 | -3.1953 | 473.0155 | -3.9645 |
| 08-MAR-85 | 472.5920 | -2.1080 | 470.8125 | -2.3475 | 471.7792 | -3.2208 | 472.9977 | -3.9823 |
| 21-MAR-85 | 472.5577 | -2.1423 | 470.7816 | -2.3784 | 471.7488 | -3.2512 | 472.9809 | -3.9991 |
| 13-APR-85 | 472.4974 | -2.2026 | 470.7255 | -2.4345 | 471.6948 | -3.3052 | 472.9450 | -4.0350 |
| 17-MAY-85 | 472.4336 | -2.2664 | 470.6667 | -2.4933 | 471.6317 | -3.3683 | 472.8747 | -4.1053 |
| 31-MAY-85 | 472.3956 | -2.3044 | 470.6320 | -2.5280 | 471.5937 | -3.4063 | 472.8270 | -4.1530 |
| 03-JUL-85 | 471.9511 | -2.7489 | 470.3156 | -2.8444 | 471.2511 | -3.7489 | 472.6230 | -4.3570 |
| 25-JUL-85 | 471.7931 | -2.9069 | 470.2077 | -2.9523 | 471.1423 | -3.8577 | 472.5670 | -4.4130 |
| 23-AUG-85 | 471.6422 | -3.0578 | 470.1122 | -3.0478 | 471.0491 | -3.9509 | 472.5311 | -4.4489 |
| 24-SEP-85 | 471.6415 | -3.0585 | 470.1125 | -3.0475 | 471.0490 | -3.9510 | 472.5121 | -4.4679 |
| 17-NOV-85 | 471.6127 | -3.0873 | 470.0891 | -3.0709 | 471.0190 | -3.9810 | 472.4844 | -4.4956 |
| 19-DEC-85 | 471.5942 | -3.1058 | 470.0743 | -3.0857 | 471.0018 | -3.9982 | 472.4751 | -4.5049 |
| 18-JAN-86 | 471.5817 | -3.1183 | 470.0640 | -3.0960 | 470.9921 | -4.0079 | 472.4703 | -4.5097 |
| 01-APR-86 | 471.5466 | -3.1534 | 470.0363 | -3.1237 | 470.9558 | -4.0442 | 472.4397 | -4.5403 |
| 23-JUL-86 | 471.5338 | -3.1662 | 470.0244 | -3.1356 | 470.9386 | -4.0614 | 472.4036 | -4.5764 |
| 28-OCT-86 | 471.5328 | -3.1672 | 470.0251 | -3.1349 | 470.9322 | -4.0678 | 472.4045 | -4.5755 |
| 06-MAY-87 | 471.5240 | -3.1760 | 470.0163 | -3.1437 | 470.9280 | -4.0720 | 472.4011 | -4.5789 |

NOTE.--Blanks indicate no data taken.

TABLE A-2. - Elevations and vertical displacements of foundation A, feet

| | Survey point A1 | | Survey point A2 | | Survey point A3 | | Survey point A4 | |
|---|---|---|---|---|---|---|---|---|
| | Elev | Change | Elev | Change | Elev | Change | Elev | Change |
| 07-DEC-84 | 474.0400 | 0.0000 | 474.0500 | 0.0000 | 474.0500 | 0.0000 | 474.0300 | 0.0000 |
| 26-DEC-84 | 474.0252 | -.0148 | 474.0461 | -.0039 | 474.0425 | -.0075 | 474.0256 | -.0044 |
| 04-JAN-85 | 474.0400 | .0000 | | | | | | |
| 07-JAN-85 | 474.0000 | -.0400 | | | | | | |
| 08-JAN-85 | 474.0000 | -.0400 | 474.0200 | -.0300 | 474.0200 | -.0300 | 474.0100 | -.0200 |
| 14-JAN-85 | 474.0011 | -.0389 | 474.0329 | -.0171 | 474.0318 | -.0182 | 474.0170 | -.0130 |
| 15-JAN-85 | 473.9793 | -.0607 | 474.0169 | -.0331 | 474.0184 | -.0316 | 474.0034 | -.0266 |
| 16-JAN-85 | 473.9707 | -.0693 | 474.0111 | -.0389 | 474.0156 | -.0344 | 474.0012 | -.0288 |
| 17-JAN-85 | 473.9583 | -.0817 | 474.0008 | -.0492 | 474.0063 | -.0437 | 473.9930 | -.0370 |
| 18-JAN-85 | 473.9364 | -.1036 | 473.9827 | -.0673 | 473.9949 | -.0551 | 473.9807 | -.0493 |
| 19-JAN-85 | 473.9118 | -.1282 | 473.9618 | -.0882 | 473.9775 | -.0725 | 473.9644 | -.0656 |
| 21-JAN-85 | 473.8623 | -.1777 | 473.9288 | -.1212 | 473.9477 | -.1023 | 473.9367 | -.0933 |
| 22-JAN-85 | 473.8021 | -.2379 | 473.8872 | -.1628 | 473.9184 | -.1316 | 473.9077 | -.1223 |
| 23-JAN-85 | 473.7812 | -.2588 | 473.8740 | -.1760 | 473.9108 | -.1392 | 473.9005 | -.1295 |
| 24-JAN-85 | 473.7515 | -.2885 | 473.8486 | -.2014 | 473.8698 | -.1802 | 473.8791 | -.1509 |
| 25-JAN-85 | 473.7323 | -.3077 | 473.8320 | -.2180 | 473.8768 | -.1732 | 473.8664 | -.1636 |
| 28-JAN-85 | 473.6715 | -.3685 | 473.7810 | -.2690 | 473.8331 | -.2169 | 473.8218 | -.2082 |
| 29-JAN-85 | 473.6842 | -.3558 | 473.7974 | -.2526 | 473.8527 | -.1973 | 473.8435 | -.1865 |
| 30-JAN-85 | 473.6554 | -.3846 | 473.7707 | -.2793 | 473.8266 | -.2234 | 473.8161 | -.2139 |
| 31-JAN-85 | 473.5820 | -.4580 | 473.7080 | -.3420 | 473.7805 | -.2695 | 473.7748 | -.2552 |
| 01-FEB-85 | 472.8149 | -1.2251 | 473.0816 | -.9684 | 473.2878 | -.7622 | 473.3257 | -.7043 |
| 02-FEB-85 | 472.4417 | -1.5983 | 472.7710 | -1.2790 | 473.0475 | -1.0025 | 473.0924 | - .9376 |
| 03-FEB-85 | 472.3177 | -1.7223 | 472.6630 | -1.3870 | 472.9557 | -1.0943 | 473.0004 | -1.0296 |
| 04-FEB-85 | 472.2794 | -1.7606 | 472.6321 | -1.4179 | 472.9322 | -1.1178 | 472.9769 | -1.0531 |
| 05-FEB-85 | 472.2103 | -1.8297 | 472.5682 | -1.4818 | 472.8736 | -1.1764 | 472.9183 | -1.1117 |
| 06-FEB-85 | 472.1783 | -1.8617 | 472.5376 | -1.5124 | 472.8473 | -1.2027 | 472.8901 | -1.1399 |
| 07-FEB-85 | 472.1480 | -1.8920 | 472.5099 | -1.5401 | 472.8229 | -1.2271 | 472.8661 | -1.1639 |
| 08-FEB-85 | 472.1270 | -1.9130 | 472.4925 | -1.5575 | 472.8080 | -1.2420 | 472.8509 | -1.1791 |
| 13-FEB-85 | 472.0610 | -1.9790 | 472.4283 | -1.6217 | 472.7488 | -1.3012 | 472.7914 | -1.2386 |
| 15-FEB-85 | 472.0434 | -1.9966 | 472.4126 | -1.6374 | 472.7371 | -1.3129 | 472.7815 | -1.2485 |
| 19-FEB-85 | 472.0268 | -2.0132 | 472.3950 | -1.6550 | 472.7208 | -1.3292 | 472.7643 | -1.2657 |
| 22-FEB-85 | 472.0293 | -2.0107 | 472.3991 | -1.6509 | 472.7262 | -1.3238 | 472.7705 | -1.2595 |
| 26-FEB-85 | 472.0066 | -2.0334 | 472.3781 | -1.6719 | 472.7087 | -1.3413 | 472.7518 | -1.2782 |
| 8-MAR-85 | 471.9728 | -2.0672 | 472.3463 | -1.7037 | 472.6801 | -1.3699 | 472.7217 | -1.3083 |
| 21-MAR-85 | 471.9427 | -2.0973 | 472.3159 | -1.7341 | 472.6513 | -1.3987 | 472.6903 | -1.3397 |
| 13-APR-85 | 471.8809 | -2.1591 | 472.2585 | -1.7915 | 472.5963 | -1.4537 | 472.6371 | -1.3929 |
| 17-MAY-85 | 471.8165 | -2.2235 | 472.1947 | -1.8553 | 472.5366 | -1.5134 | 472.5751 | -1.4549 |
| 31-MAY-85 | 471.7801 | -2.2599 | 472.1616 | -1.8884 | 472.5063 | -1.5437 | 472.5452 | -1.4848 |
| 03-JUL-85 | 471.3924 | -2.6476 | 471.8222 | -2.2278 | 472.2190 | -1.8310 | 472.2360 | -1.7940 |
| 25-JUL-85 | 471.2542 | -2.7858 | 471.6921 | -2.3579 | 472.1026 | -1.9474 | 472.1064 | -1.9236 |
| 23-AUG-85 | 471.1258 | -2.9142 | 471.5694 | -2.4806 | 471.9878 | -2.0622 | 471.9759 | -2.0541 |
| 24-SEP-85 | 471.1162 | -2.9238 | 471.5590 | -2.4910 | 471.9783 | -2.0717 | 471.9687 | -2.0613 |
| 17-NOV-85 | 471.0917 | -2.9483 | 471.5393 | -2.5107 | 471.9557 | -2.0943 | 471.9424 | -2.0876 |
| 19-DEC-85 | 471.0771 | -2.9629 | 471.5223 | -2.5277 | 471.9459 | -2.1041 | 471.9321 | -2.0979 |
| 18-JAN-86 | 471.0654 | -2.9746 | 471.5111 | -2.5389 | 471.9347 | -2.1153 | 471.9183 | -2.1117 |
| 01-APR-86 | 471.0292 | -3.0108 | 471.4775 | -2.5725 | 471.9032 | -2.1468 | 471.8839 | -2.1461 |
| 23-JUL-86 | 471.0238 | -3.0162 | 471.4704 | -2.5796 | 471.8938 | -2.1562 | 471.8740 | -2.1560 |
| 28-OCT-86 | 471.0181 | -3.0219 | 471.4648 | -2.5852 | 471.8898 | -2.1602 | 471.8696 | -2.1604 |
| 06-MAY-87 | 471.0117 | 3.0283 | 471.4583 | -2.5917 | 471.8840 | -2.1660 | 471.8634 | -2.1666 |

See explanatory notes at end of table.

TABLE A-2. - Elevations and vertical displacements of foundation A, feet--Continued

| | Survey point A5 | | Survey point A6 | | Survey point A7 | | Survey point A8 | |
|---|---|---|---|---|---|---|---|---|
| | Elev | Change | Elev | Change | Elev | Change | Elev | Change |
| 07-DEC-84 | 474.0500 | 0.0000 | 474.0400 | 0.0000 | 474.0700 | 0.0000 | 474.0500 | 0.0000 |
| 26-DEC-84 | 474.0446 | -.0054 | 474.0319 | -.0081 | 474.0557 | -.0143 | 474.0353 | -.0147 |
| 04-JAN-85 | | | | | 474.0700 | .0000 | 474.0500 | .0000 |
| 07-JAN-85 | | | | | 474.0300 | -.0400 | 474.0100 | -.0400 |
| 08-JAN-85 | 474.0300 | -.0200 | 474.0100 | -.0300 | 474.0300 | -.0400 | 474.0100 | -.0400 |
| 14-JAN-85 | 474.0370 | -.0130 | 474.0192 | -.0208 | 474.0358 | -.0342 | 474.0149 | -.0351 |
| 15-JAN-85 | 474.0232 | -.0268 | 474.0029 | -.0371 | 474.0163 | -.0537 | 473.9927 | -.0573 |
| 16-JAN-85 | 474.0199 | -.0301 | 473.9982 | -.0418 | 474.0088 | -.0612 | 473.9846 | -.0654 |
| 17-JAN-85 | 474.0130 | -.0370 | 473.9899 | -.0501 | 473.9976 | -.0724 | 473.9735 | -.0765 |
| 18-JAN-85 | 474.0020 | -.0480 | 473.9761 | -.0639 | 473.9773 | -.0927 | 473.9510 | -.0990 |
| 19-JAN-85 | 473.9877 | -.0623 | 473.9567 | -.0833 | 473.9554 | -.1146 | 473.9284 | -.1216 |
| 21-JAN-85 | 473.9570 | -.0930 | 473.9207 | -.1193 | 473.9156 | -.1544 | 473.8831 | -.1669 |
| 22-JAN-85 | 473.9293 | -.1207 | 473.8851 | -.1549 | 473.8675 | -.2025 | 473.8296 | -.2204 |
| 23-JAN-85 | 473.9212 | -.1288 | 473.8728 | -.1672 | 473.8484 | -.2216 | 473.8097 | -.2403 |
| 24-JAN-85 | 473.8791 | -.1709 | 473.8474 | -.1926 | 473.8374 | -.2326 | 473.7789 | -.2711 |
| 25-JAN-85 | 473.8874 | -.1626 | 473.8334 | -.2066 | 473.7979 | -.2721 | 473.7594 | -.2906 |
| 28-JAN-85 | 473.8454 | -.2046 | 473.7850 | -.2550 | 473.7388 | -.3312 | 473.6988 | -.3512 |
| 29-JAN-85 | 473.8665 | -.1835 | 473.8031 | -.2369 | 473.7546 | -.3154 | 473.7135 | -.3365 |
| 30-JAN-85 | 473.8395 | -.2105 | 473.7757 | -.2643 | 473.7237 | -.3463 | 473.6837 | -.3663 |
| 31-JAN-85 | 473.8026 | -.2474 | 473.7260 | -.3140 | 473.6620 | -.4080 | 473.6143 | -.4357 |
| 01-FEB-85 | 473.3924 | -.6576 | 473.1970 | -.8430 | 473.0079 | -1.0621 | 472.8998 | -1.1502 |
| 02-FEB-85 | 473.1704 | -.8796 | 472.9036 | -1.1364 | 472.6491 | -1.4209 | 472.5303 | -1.5197 |
| 03-FEB-85 | 473.0771 | -.9729 | 472.7948 | -1.2452 | 472.5251 | -1.5449 | 472.4060 | -1.6440 |
| 04-FEB-85 | 473.0536 | -.9964 | 472.7625 | -1.2775 | 472.4862 | -1.5838 | 472.3680 | -1.6820 |
| 05-FEB-85 | 472.9953 | -1.0547 | 472.6985 | -1.3415 | 472.4171 | -1.6529 | 472.2984 | -1.7516 |
| 06-FEB-85 | 472.9650 | -1.0850 | 472.6641 | -1.3759 | 472.3809 | -1.6891 | 472.2640 | -1.7860 |
| 07-FEB-85 | 472.9416 | -1.1084 | 472.6373 | -1.4027 | 472.3511 | -1.7189 | 472.2344 | -1.8156 |
| 08-FEB-85 | 472.9266 | -1.1234 | 472.6205 | -1.4195 | 472.3320 | -1.7380 | 472.2143 | -1.8357 |
| 13-FEB-85 | 472.8641 | -1.1859 | 472.5530 | -1.4870 | 472.2620 | -1.8080 | 472.1468 | -1.9032 |
| 15-FEB-85 | 472.8530 | -1.1970 | 472.5399 | -1.5001 | 472.2450 | -1.8250 | 472.1287 | -1.9213 |
| 19-FEB-85 | 472.8348 | -1.2152 | 472.5203 | -1.5197 | 472.2282 | -1.8418 | 472.1100 | -1.9400 |
| 22-FEB-85 | 472.8443 | -1.2057 | 472.5278 | -1.5122 | 472.2302 | -1.8398 | 472.1158 | -1.9342 |
| 26-FEB-85 | 472.8289 | -1.2211 | 472.5099 | -1.5301 | 472.2110 | -1.8590 | 472.0951 | -1.9549 |
| 08-MAR-85 | 472.7976 | -1.2524 | 472.4763 | -1.5637 | 472.1766 | -1.8934 | 472.0623 | -1.9877 |
| 21-MAR-85 | 472.7650 | -1.2850 | 472.4430 | -1.5970 | 472.1454 | -1.9246 | 472.0303 | -2.0197 |
| 13-APR-85 | 472.7117 | -1.3383 | 472.3861 | -1.6539 | 472.0828 | -1.9872 | 471.9701 | -2.0799 |
| 17-MAY-85 | 472.6471 | -1.4029 | 472.3183 | -1.7217 | 472.0143 | -2.0557 | 471.9029 | -2.1471 |
| 31-MAY-85 | 472.6168 | -1.4332 | 472.2847 | -1.7553 | 471.9776 | -2.0924 | 471.8664 | -2.1836 |
| 03-JUL-85 | 472.2871 | -1.7629 | 471.8896 | -2.1504 | 471.5176 | -2.5524 | 471.4455 | -2.6045 |
| 25-JUL-85 | 472.1441 | -1.9059 | 471.7285 | -2.3115 | 471.3434 | -2.7266 | 471.2913 | -2.7587 |
| 23-AUG-85 | 471.9934 | -2.0566 | 471.5672 | -2.4728 | 471.1746 | -2.8954 | 471.1063 | -2.9437 |
| 24-SEP-85 | 471.9855 | -2.0645 | 471.5593 | -2.4807 | 471.1659 | -2.9041 | 471.1375 | -2.9125 |
| 17-NOV-85 | 471.9590 | -2.0910 | 471.5317 | -2.5083 | 471.1363 | -2.9337 | 471.1104 | -2.9396 |
| 19-DEC-85 | 471.9446 | -2.1054 | 471.5148 | -2.5252 | 471.1195 | -2.9505 | 471.0939 | -2.9561 |
| 18-JAN-86 | 471.9337 | -2.1163 | 471.5033 | -2.5367 | 471.1069 | -2.9631 | 471.0814 | -2.9686 |
| 01-APR-86 | 471.8974 | -2.1526 | 471.4638 | -2.5762 | 471.0657 | -3.0043 | 471.0438 | -3.0062 |
| 23-JUL-86 | 471.8885 | -2.1615 | 471.4765 | -2.5635 | 471.0776 | -2.9934 | 471.0387 | -3.0113 |
| 28-OCT-86 | 471.8892 | -2.1608 | 471.4502 | -2.5898 | 471.0500 | -3.0200 | 471.0306 | -3.0194 |
| 06-MAY-87 | 471.8758 | -2.1742 | 471.4416 | -2.5984 | 471.0442 | -3.0258 | 471.0246 | -3.0254 |

NOTE.--Blanks indicate no data taken.

TABLE A-3. - Elevations and vertical displacements of foundation B, feet

| | Survey point B1 | | Survey point B2 | | Survey point B3 | | Survey point B4 | |
|---|---|---|---|---|---|---|---|---|
| | Elev | Change | Elev | Change | Elev | Change | Elev | Change |
| 07-DEC-84 | 472.0800 | 0.0000 | 472.0800 | 0.0000 | 472.0700 | 0.0000 | 472.0600 | 0.0000 |
| 26-DEC-84 | 472.0626 | -.0174 | 472.0799 | -.0001 | 472.0739 | -.0039 | 472.0589 | -.0011 |
| 04-JAN-85 | 472.0400 | -.0400 | | | | | | |
| 07-JAN-85 | 472.0400 | -.0400 | | | | | | |
| 08-JAN-85 | 472.0400 | -.0400 | 472.0500 | -.0300 | 472.0500 | -.0200 | 472.0300 | -.0300 |
| 15-JAN-85 | 471.9999 | -.0801 | 472.0290 | -.0510 | 472.0302 | -.0398 | 472.0181 | -.0419 |
| 16-JAN-85 | 471.9879 | -.0921 | 472.0210 | -.0590 | 472.0254 | -.0446 | 472.0138 | -.0462 |
| 17-JAN-85 | 471.9792 | -.1008 | 472.0123 | -.0677 | 472.0162 | -.0538 | 472.0052 | -.0548 |
| 18-JAN-85 | 471.9488 | -.1312 | 471.9907 | -.0893 | 472.0073 | -.0627 | 471.9954 | -.0646 |
| 19-JAN-85 | 471.9232 | -.1568 | 471.9704 | -.1096 | 471.9854 | -.0846 | 471.9729 | -.0871 |
| 21-JAN-85 | 471.8570 | -.2230 | 471.9193 | -.1607 | 471.9437 | -.1263 | 471.9384 | -.1216 |
| 22-JAN-85 | 471.7708 | -.3092 | 471.8631 | -.2169 | 471.9089 | -.1611 | 471.9052 | -.1548 |
| 23-JAN-85 | 471.7460 | -.3340 | 471.8480 | -.2320 | 471.9012 | -.1688 | 471.8985 | -.1615 |
| 24-JAN-85 | 471.7128 | -.3672 | 471.8223 | -.2577 | 471.8783 | -.1917 | 471.8756 | -.1844 |
| 25-JAN-85 | 471.6919 | -.3881 | 471.8052 | -.2748 | 471.8649 | -.2051 | 471.8626 | -.1974 |
| 28-JAN-85 | 471.6292 | -.4508 | 471.7525 | -.3275 | 471.8200 | -.2500 | 471.8191 | -.2409 |
| 29-JAN-85 | 471.6422 | -.4378 | 471.7688 | -.3112 | 471.8375 | -.2325 | 471.8393 | -.2207 |
| 30-JAN-85 | 471.6110 | -.4690 | 471.7416 | -.3384 | 471.8102 | -.2598 | 471.8122 | -.2478 |
| 31-JAN-85 | 471.5171 | -.5629 | 471.6652 | -.4148 | 471.7516 | -.3184 | 471.7555 | -.3045 |
| 01-FEB-85 | 470.5913 | -1.4887 | 470.8915 | -1.1885 | 471.1395 | -.9305 | 471.1800 | -.8800 |
| 02-FEB-85 | 470.2288 | -1.8512 | 470.5856 | -1.4944 | 470.8982 | -1.1718 | 470.9368 | -1.1232 |
| 03-FEB-85 | 470.1162 | -1.9638 | 470.4849 | -1.5951 | 470.8137 | -1.2563 | 470.8514 | -1.2086 |
| 04-FEB-85 | 470.0818 | -1.9982 | 470.4553 | -1.6247 | 470.7934 | -1.2766 | 470.8308 | -1.2292 |
| 05-FEB-85 | 470.0160 | -2.0640 | 470.3952 | -1.6848 | 470.7375 | -1.3325 | 470.7749 | -1.2851 |
| 06-FEB-85 | 469.9884 | -2.0916 | 470.3698 | -1.7102 | 470.7163 | -1.3537 | 470.7519 | -1.3081 |
| 07-FEB-85 | 469.9554 | -2.1246 | 470.3395 | -1.7405 | 470.6901 | -1.3799 | 470.7246 | -1.3354 |
| 08-FEB-85 | 469.9411 | -2.1389 | 470.3257 | -1.7543 | 470.6777 | -1.3923 | 470.7129 | -1.3471 |
| 13-FEB-85 | 469.8752 | -2.2048 | 470.2635 | -1.8165 | 470.6226 | -1.4474 | 470.6570 | -1.4030 |
| 15-FEB-85 | 469.8609 | -2.2191 | 470.2566 | -1.8234 | 470.6100 | -1.4600 | 470.6472 | -1.4128 |
| 19-FEB-85 | 469.8460 | -2.2340 | 470.2433 | -1.8367 | 470.5984 | -1.4716 | 470.6332 | -1.4268 |
| 22-FEB-85 | 469.8484 | -2.2316 | 470.2456 | -1.8344 | 470.6000 | -1.4700 | 470.6333 | -1.4267 |
| 26-FEB-85 | 469.8270 | -2.2530 | 470.2172 | -1.8628 | 470.5772 | -1.4928 | 470.6016 | -1.4584 |
| 08-MAR-85 | 469.7982 | -2.2818 | 470.1880 | -1.8920 | 470.5509 | -1.5191 | 470.5743 | -1.4857 |
| 21-MAR-85 | 469.7680 | -2.3120 | 470.1598 | -1.9202 | 470.5243 | -1.5457 | 470.5460 | -1.5140 |
| 13-APR-85 | 469.7132 | -2.3668 | 470.1066 | -1.9734 | 470.4736 | -1.5964 | 470.4939 | -1.5661 |
| 17-MAY-85 | 469.6562 | -2.4238 | 470.0514 | -2.0286 | 470.4219 | -1.6481 | 470.4415 | -1.6185 |
| 31-MAY-85 | 469.6220 | -2.4580 | 470.0187 | -2.0613 | 470.3904 | -1.6796 | 470.4094 | -1.6506 |
| 03-JUL-85 | 469.3401 | -2.7399 | 469.7680 | -2.3120 | 470.1756 | -1.8944 | 470.1773 | -1.8827 |
| 25-JUL-85 | 469.2460 | -2.8340 | 469.6772 | -2.4028 | 470.0962 | -1.9738 | 470.0877 | -1.9723 |
| 23-AUG-85 | 469.1607 | -2.9193 | 469.5976 | -2.4824 | 470.0174 | -2.0526 | 470.0061 | -2.0539 |
| 24-SEP-85 | 469.1613 | -2.9187 | 469.5932 | -2.4868 | 470.0104 | -2.0596 | 470.0033 | -2.0567 |
| 17-NOV-85 | 469.1376 | -2.9424 | 469.5716 | -2.5084 | 469.9903 | -2.0797 | 469.9815 | -2.0785 |
| 19-DEC-85 | 469.1233 | -2.9567 | 469.5611 | -2.5189 | 469.9825 | -2.0875 | 469.9737 | -2.0863 |
| 18-JAN-86 | 469.1125 | -2.9675 | 469.5498 | -2.5302 | 469.9758 | -2.0942 | 469.9620 | -2.0980 |
| 01-APR-86 | 469.0843 | -2.9957 | 469.5224 | -2.5576 | 469.9528 | -2.1172 | 469.9358 | -2.1242 |
| 23-JUL-86 | 469.0727 | -3.0073 | 469.5108 | -2.5692 | 469.9431 | -2.1269 | 469.9256 | -2.1344 |
| 28-OCT-86 | 469.0704 | -3.0096 | 469.5069 | -2.5731 | 469.9380 | -2.1320 | 469.9276 | -2.1324 |
| 06-MAY-87 | 469.0661 | -3.0139 | 469.5037 | -2.5763 | 469.9358 | -2.1342 | 469.9181 | -2.1369 |

See explanatory note at end of table.

TABLE A-3. - Elevations and vertical displacements of foundation B, feet--Continued

| | Survey point B5 | | Survey point B6 | | Survey point B7 | | Survey point B8 | |
|---|---|---|---|---|---|---|---|---|
| | Elev | Change | Elev | Change | Elev | Change | Elev | Change |
| 07-DEC-84 | 472.1000 | 0.0000 | 472.1000 | 0.0000 | 472.1200 | 0.0000 | 472.1000 | 0.0000 |
| 26-DEC-84 | 472.1006 | .0006 | 472.0956 | .0044 | 472.1089 | .0111 | 472.0850 | .0150 |
| 04-JAN-85 | | | | | 472.0800 | .0400 | 472.0500 | .0500 |
| 07-JAN-85 | | | | | 472.0800 | .0400 | 472.0600 | .0400 |
| 08-JAN-85 | 472.0700 | -.0300 | 472.0700 | .0300 | 472.0800 | .0400 | 472.0600 | .0400 |
| 15-JAN-85 | 472.0627 | -.0373 | 472.0494 | .0506 | 472.0550 | .0650 | 473.0263 | .0737 |
| 16-JAN-85 | 472.0583 | -.0417 | 472.0432 | .0568 | 472.0437 | .0763 | 472.0153 | .0847 |
| 17-JAN-85 | 472.0509 | -.0491 | 472.0349 | .0651 | 472.0349 | .0851 | 472.0064 | .0936 |
| 18-JAN-85 | 472.0390 | -.0610 | 472.0181 | .0819 | 472.0101 | .1099 | 471.9813 | .1187 |
| 19-JAN-85 | 472.0195 | -.0805 | 471.9933 | .1067 | 471.9853 | .1347 | 471.9509 | .1491 |
| 21-JAN-85 | 471.9812 | -.1188 | 471.9499 | .1501 | 471.9335 | .1865 | 471.8942 | .2058 |
| 22-JAN-85 | 471.9481 | -.1519 | 471.9037 | .1963 | 471.8652 | .2548 | 471.8166 | .2834 |
| 23-JAN-85 | 471.9401 | -.1599 | 471.8891 | .2109 | 471.8433 | .2767 | 471.7941 | .3059 |
| 24-JAN-85 | 471.9178 | -.1822 | 471.8624 | .2376 | 471.8105 | .3095 | 471.7632 | .3368 |
| 25-JAN-85 | 471.9032 | -.1968 | 471.8459 | .2541 | 471.7895 | .3305 | 471.7442 | .3558 |
| 28-JAN-85 | 471.8592 | -.2408 | 471.7937 | .3063 | 471.7289 | .3911 | 471.6824 | .4176 |
| 29-JAN-85 | 471.8775 | -.2225 | 471.8122 | .2878 | 471.7424 | .3776 | 471.6966 | .4034 |
| 30-JAN-85 | 471.8510 | -.2490 | 471.7842 | .3158 | 471.7118 | .4082 | 471.6659 | .4341 |
| 31-JAN-85 | 471.8000 | -.3000 | 471.7167 | .3833 | 471.6285 | .4915 | 471.5792 | .5208 |
| 01-FEB-85 | 471.2562 | -.8438 | 471.0142 | 1.0858 | 470.7871 | 1.3329 | 470.6914 | 1.4086 |
| 02-FEB-85 | 471.0144 | -1.0856 | 470.7000 | 1.4000 | 470.4140 | 1.7060 | 470.3227 | 1.7773 |
| 03-FEB-85 | 470.9276 | -1.1724 | 470.5992 | 1.5008 | 470.2974 | 1.8226 | 470.2074 | 1.8926 |
| 04-FEB-85 | 470.9068 | -1.1932 | 470.5676 | 1.5324 | 470.2590 | 1.8610 | 470.1717 | 1.9283 |
| 05-FEB-85 | 470.8498 | -1.2502 | 470.5037 | 1.5963 | 470.1895 | 1.9305 | 470.1040 | 1.9960 |
| 06-FEB-85 | 470.8278 | -1.2722 | 470.4769 | 1.6231 | 470.1591 | 1.9609 | 470.0751 | 2.0249 |
| 07-FEB-85 | 470.7999 | -1.3001 | 470.4461 | 1.6539 | 470.1244 | 1.9956 | 470.0412 | 2.0588 |
| 08-FEB-85 | 470.7873 | -1.3127 | 470.4339 | 1.6661 | 470.1104 | 2.0096 | 470.0270 | 2.0730 |
| 13-FEB-85 | 470.7281 | -1.3719 | 470.3698 | 1.7302 | 470.0422 | 2.0778 | 469.9624 | 2.1376 |
| 15-FEB-85 | 470.7154 | -1.3846 | 470.3568 | 1.7432 | 470.0303 | 2.0897 | 469.9490 | 2.1510 |
| 19-FEB-85 | 470.6949 | -1.4051 | 470.3343 | 1.7657 | 470.0123 | 2.1077 | 469.9350 | 2.1650 |
| 22-FEB-85 | 470.6952 | -1.4048 | 470.3272 | 1.7728 | 470.0045 | 2.1155 | 469.9339 | 2.1661 |
| 26-FEB-85 | 470.6769 | -1.4231 | 470.3025 | 1.7975 | 469.9787 | 2.1413 | 469.9015 | 2.1985 |
| 08-MAR-85 | 470.6500 | -1.4500 | 470.2773 | 1.8227 | 469.9489 | 2.1711 | 469.8720 | 2.2280 |
| 21-MAR-85 | 470.6210 | -1.4790 | 470.2421 | 1.8579 | 469.9171 | 2.2029 | 469.8406 | 2.2594 |
| 13-APR-85 | 470.5678 | -1.5322 | 470.1859 | 1.9141 | 469.8596 | 2.2604 | 469.7848 | 2.3152 |
| 17-MAY-85 | 470.5149 | -1.5851 | 470.1286 | 1.9714 | 469.8002 | 2.3198 | 469.7259 | 2.3741 |
| 31-MAY-85 | 470.4821 | -1.6179 | 470.0939 | 2.0061 | 469.7647 | 2.3553 | 469.6915 | 2.4085 |
| 03-JUL-85 | 470.2306 | -1.8694 | 469.7954 | 2.3046 | 469.4289 | 2.6911 | 469.3869 | 2.7131 |
| 25-JUL-85 | 470.1320 | -1.9680 | 469.6844 | 2.4156 | 469.3118 | 2.8082 | 469.2814 | 2.8186 |
| 23-AUG-85 | 470.0393 | -2.0607 | 469.5838 | 2.5162 | 469.2036 | 2.9164 | 469.1881 | 2.9119 |
| 24-SEP-85 | 470.0370 | -2.0630 | 469.5822 | 2.5178 | 469.2060 | 2.9140 | 469.1875 | 2.9125 |
| 17-NOV-85 | 470.0122 | -2.0878 | 469.5572 | 2.5428 | 469.1773 | 2.9427 | 469.1637 | 2.9363 |
| 19-DEC-85 | 470.0001 | -2.0999 | 469.5427 | 2.5573 | 469.1627 | 2.9573 | 469.1490 | 2.9510 |
| 18-JAN-86 | 469.9918 | -2.1082 | 469.5318 | 2.5682 | 469.1515 | 2.9685 | 469.1385 | 2.9615 |
| 01-APR-86 | 469.9644 | -2.1356 | 469.5003 | 2.5997 | 469.1190 | 3.0010 | 469.1076 | 2.9924 |
| 23-JUL-86 | 469.9516 | -2.1484 | 469.4881 | 2.6119 | 469.1075 | 3.0125 | 469.0966 | 3.0034 |
| 28-OCT-86 | 469.9497 | -2.1503 | 469.4855 | 2.6145 | 469.1021 | 3.0179 | 469.0919 | 3.0081 |
| 06-MAY-87 | 469.9459 | -2.1541 | 469.4801 | 2.6199 | 469.0996 | 3.0204 | 469.0895 | 3.0125 |

NOTE.--Blanks indicate no data taken.

## APPENDIX B.--HORIZONTAL MOVEMENTS AND DIRECTIONS

TABLE B-1. - Horizontal movements[1] and directions for site foundations and east-west base line

| Monument or survey point | 2/15/85 | | 7/25/85 | | 10/28/86 | |
|---|---|---|---|---|---|---|
| | Movement, ft | Direction, deg azimuth | Movement, ft | Direction, deg azimuth | Movement, ft | Direction, deg azimuth |
| SITE | | | | | | |
| B..... | 0.09 | 186.3400 | | | 0.34 | 261.6338 |
| C..... | .03 | 146.3100 | | | .22 | 259.6905 |
| D..... | .06 | 51.3400 | | | .34 | 297.2930 |
| F..... | .42 | 43.0900 | 0.19 | 287.2930 | .57 | 332.1017 |
| J..... | .44 | 60.5700 | .26 | 240.5200 | .35 | 305.9058 |
| K..... | .31 | 67.5200 | .23 | 223.2600 | .29 | 281.6870 |
| L..... | .45 | 33.3400 | .24 | 289.1800 | .66 | 326.0689 |
| FOUNDATION | | | | | | |
| A1..... | .51 | 44.2100 | .17 | 276.7100 | .57 | 329.8852 |
| A2..... | .48 | 28.1400 | .07 | 270.0000 | .63 | 330.5890 |
| A3..... | .42 | 28.3900 | .11 | 329.0400 | .68 | 332.3180 |
| A4..... | .45 | 36.1200 | .15 | 304.7000 | .57 | 339.6728 |
| A5..... | .41 | 27.1800 | .05 | 338.2000 | .60 | 332.5889 |
| A6..... | .43 | 28.9300 | .07 | 285.9500 | .61 | 333.0185 |
| A7..... | .46 | 40.6000 | .14 | 303.6900 | .64 | 337.0352 |
| A8..... | .47 | 47.5600 | .12 | 284.0400 | .55 | 338.9575 |
| B1..... | .56 | 28.3700 | .15 | 273.8100 | .65 | 333.8215 |
| B2..... | .58 | 24.3600 | .15 | 238.3900 | .63 | 333.0338 |
| B3..... | .39 | 11.5900 | .13 | 300.2600 | .73 | 325.0048 |
| B4..... | .49 | 29.1700 | .18 | 273.1800 | .61 | 333.0185 |
| B5..... | .50 | 27.0700 | .11 | 259.7000 | .59 | 333.8680 |
| B6..... | .45 | 24.8600 | .14 | 254.0500 | .60 | 333.4343 |
| B7..... | .48 | 34.0200 | .21 | 259.2200 | .49 | 332.4017 |
| B8..... | .43 | 36.6100 | .11 | 259.7000 | .51 | 330.9405 |
| BASE LINE | | | | | | |
| 1..... | .06 | 72 | .18 | 77 | .23 | 306 |
| 2..... | .17 | 66 | .30 | 47 | .37 | 326 |
| 3..... | .36 | 51 | .42 | 24 | .59 | 323 |
| 4..... | .44 | 28 | .49 | 12 | .54 | 346 |
| 5..... | .47 | 5 | .54 | 346 | .79 | 324 |
| 6..... | .45 | 323 | .52 | 315 | .88 | 301 |
| 7..... | .10 | 270 | .22 | 260 | .59 | 282 |
| 8..... | .04 | 180 | .13 | 224 | .42 | 277 |
| 9..... | .06 | 180 | .16 | 210 | .38 | 261 |
| 10..... | .04 | 180 | .20 | 228 | .42 | 269 |

[1]From December 7, 1984, measurement.

NOTE.--Blanks indicate no data taken.

## APPENDIX C.--TILT DIRECTIONS AND MAGNITUDES

TABLE C-1. - Tilt magnitudes and directions for foundation A, degrees

| | Tiltplate A1 | | Tiltplate A2 | | Tiltplate A3 | | Tiltplate A4 | | Tiltplate A5 | | Tiltplate A6 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tilt | Direc-tion | Tilt | Direc-tion | Tilt | Direc-tion | Tilt | Direc-tion | Tilt | Direc-tion | Tilt | Direc-tion |
| 19-DEC-84 | 0.0000 | 0.00 | 0.0000 | 0.00 | 0.0000 | 0.00 | 0.0000 | 0.00 | 0.0000 | 0.00 | 0.0000 | 0.00 |
| 09-JAN-85 | .0280 | 349.69 | .0716 | 24.78 | .0527 | 354.56 | .0729 | 5.91 | .0828 | 264.81 | .1176 | 272.44 |
| 14-JAN-85 | .0834 | 351.38 | .1047 | 40.16 | .0722 | 14.04 | .0831 | 6.91 | .0828 | 275.19 | .0716 | 299.25 |
| 15-JAN-85 | .1329 | 16.39 | .1574 | 46.93 | .0629 | 6.84 | .0966 | 21.25 | .1298 | 285.64 | .0583 | 300.96 |
| 16-JAN-85 | .1504 | 15.42 | .1768 | 45.00 | .0500 | 323.13 | .0775 | 20.77 | .1329 | 286.39 | .0781 | 320.19 |
| 17-JAN-85 | .1814 | 11.93 | .1822 | 43.33 | .0862 | 29.54 | .1107 | 6.48 | .0919 | 292.38 | .0840 | 329.62 |
| 18-JAN-85 | .1638 | 12.34 | .2024 | 25.62 | .1266 | 9.09 | .1139 | 351.16 | .1185 | 225.85 | .0922 | 347.47 |
| 19-JAN-85 | .1736 | 11.63 | .2161 | 41.25 | .2383 | 4.81 | .1044 | 11.04 | .1335 | 308.16 | .1141 | 331.19 |
| 22-JAN-85 | .4626 | 19.90 | .4263 | 49.65 | .0958 | 164.88 | .0527 | 174.56 | .1439 | 342.82 | .2149 | 29.25 |
| 23-JAN-85 | .4635 | 20.19 | .4561 | 45.44 | .0571 | 151.19 | .0382 | 168.69 | .1175 | 1.22 | .2725 | 37.92 |
| 24-JAN-85 | .4517 | 26.28 | .4658 | 38.90 | .0760 | 27.41 | .0781 | 7.35 | .1408 | 6.12 | .2900 | 35.88 |
| 28-JAN-85 | .5439 | 18.77 | .5480 | 40.37 | .1124 | 159.15 | .1093 | 169.46 | .2256 | 350.43 | .2943 | 9.78 |
| 29-JAN-85 | .5748 | 19.30 | .5820 | 42.74 | .2121 | 171.87 | .2431 | 175.87 | .2465 | 337.34 | .2925 | 359.02 |
| 30-JAN-85 | .5629 | 18.11 | .5731 | 35.77 | .1305 | 163.30 | .1069 | 169.22 | .2353 | 356.96 | .3228 | 16.19 |
| 31-JAN-85 | .6564 | 17.05 | .6483 | 33.20 | .0551 | 87.40 | .0594 | 75.38 | .3252 | 1.76 | .3787 | 19.27 |
| 01-FEB-85 | 1.3979 | 22.39 | 1.4369 | 27.68 | .6607 | 31.22 | .6583 | 32.12 | 1.0042 | 11.93 | 1.0297 | 21.21 |
| 02-FEB-85 | 1.6972 | 19.98 | 1.7606 | 24.85 | .9447 | 8.22 | 1.0590 | 31.29 | 1.3952 | 13.79 | 1.4705 | 18.43 |
| 04-FEB-85 | 1.8390 | 20.28 | 1.9085 | 26.20 | 1.1008 | 22.43 | 1.0684 | 24.47 | 1.4998 | 10.95 | 1.5664 | 14.44 |
| 05-FEB-85 | 1.8239 | 18.21 | 1.9061 | 23.91 | 1.1773 | 22.21 | 1.1425 | 22.24 | 1.5307 | 12.83 | 1.6137 | 16.47 |
| 06-FEB-85 | 1.8552 | 19.85 | 1.9256 | 23.57 | 1.2190 | 20.40 | 1.1890 | 21.33 | 1.5783 | 13.84 | 1.6429 | 17.99 |
| 07-FEB-85 | 1.8744 | 20.78 | 1.9551 | 24.96 | 1.1767 | 19.74 | 1.1439 | 22.08 | 1.5832 | 11.75 | 1.6307 | 15.02 |
| 08-FEB-85 | 1.9206 | 22.26 | 2.0026 | 27.43 | 1.0902 | 20.68 | 1.0387 | 23.85 | 1.5795 | 9.02 | 1.6155 | 11.61 |
| 13-FEB-85 | 1.9031 | 20.29 | 1.9878 | 23.89 | 1.2791 | 18.58 | 1.2224 | 19.47 | 1.6390 | 14.40 | 1.7118 | 19.36 |
| 15-FEB-85 | 1.8941 | 19.99 | 1.9888 | 23.96 | 1.2557 | 19.66 | 1.1429 | 20.22 | 1.6387 | 12.87 | 1.6947 | 16.19 |
| 19-FEB-85 | 1.8691 | 19.21 | 1.9897 | 21.60 | 1.3163 | 18.61 | 1.2555 | 17.86 | 1.6638 | 16.23 | 1.7335 | 19.90 |
| 22-FEB-85 | 1.9904 | 25.86 | 2.0703 | 28.17 | 1.2666 | 19.01 | 1.2175 | 20.56 | 1.6050 | 5.54 | 1.6312 | 5.01 |
| 26-FEB-85 | 2.1260 | 29.52 | 2.1600 | 32.09 | 1.2922 | 15.95 | 1.2615 | 21.02 | 1.6198 | 6.29 | 1.6490 | 6.00 |
| 05-MAR-85 | 2.1201 | 29.92 | 1.9044 | 16.86 | 1.3180 | 17.78 | 1.2670 | 20.08 | 1.5675 | 7.24 | 1.6405 | 7.88 |
| 08-MAR-85 | 2.1420 | 30.67 | 2.1939 | 33.24 | 1.3067 | 16.56 | 1.2561 | 20.38 | 1.6386 | 5.87 | 1.6513 | 5.91 |
| 21-MAR-85 | 2.1395 | 30.55 | 2.1808 | 33.07 | 1.3176 | 15.86 | 1.2542 | 19.81 | 1.6541 | 5.12 | 1.6455 | 5.67 |
| 13-APR-85 | 2.2042 | 31.22 | 2.2183 | 32.90 | 1.4035 | 17.31 | 1.2685 | 19.93 | 1.6476 | 3.22 | 1.6716 | 3.17 |
| 17-MAY-85 | 2.1965 | 30.89 | 2.2107 | 32.95 | 1.3644 | 16.61 | 1.2547 | 19.19 | 1.6751 | 359.49 | 1.6875 | 359.58 |
| 31-MAY-85 | 2.2086 | 30.40 | 2.2453 | 33.14 | 1.3767 | 12.80 | 1.2492 | 19.16 | 1.6850 | 359.74 | 1.7225 | 359.58 |
| 03-JUL-85 | 2.3531 | 25.15 | 2.4755 | 30.06 | 1.6696 | 7.57 | 1.4935 | 11.69 | 2.0838 | 349.28 | 2.0676 | 352.01 |
| 25-JUL-85 | 2.3166 | 21.86 | 2.4485 | 26.57 | 1.6736 | 3.77 | 1.4911 | 6.16 | 2.1786 | 351.55 | 2.1677 | 350.04 |
| 23-AUG-85 | 2.2777 | 17.90 | 2.4257 | 23.76 | 1.7025 | .34 | 1.5108 | 1.90 | 2.2629 | 347.88 | 2.2355 | 347.21 |
| 24-SEP-85 | 2.2274 | 16.56 | 2.3904 | 22.25 | 1.7825 | .16 | 1.5806 | 1.54 | 2.2707 | 349.47 | 2.2132 | 348.99 |
| 17-NOV-85 | 2.3022 | 18.75 | 2.4475 | 24.76 | 1.7750 | 359.60 | 1.6210 | 2.03 | 2.1680 | 347.61 | 2.2301 | 347.24 |
| 18-JAN-86 | 2.4635 | 18.03 | 2.4523 | 23.87 | 1.6085 | 357.95 | 1.3851 | .83 | 2.2527 | 350.22 | 2.1882 | 350.40 |
| 01-APR-86 | 2.4076 | 16.16 | 2.4283 | 22.71 | 1.8611 | 358.00 | 1.6325 | .00 | 2.2333 | 348.38 | 2.1575 | 347.96 |
| 23-JUL-86 | 2.4049 | 18.55 | 2.4479 | 23.24 | 1.8136 | 1.97 | 1.6100 | .27 | 2.2430 | 349.79 | 2.2252 | 350.17 |
| 28-OCT-86 | 2.3927 | 20.23 | 2.4370 | 23.20 | 1.7569 | 357.31 | 1.6402 | .79 | 2.2480 | 346.95 | 2.2147 | 346.95 |
| 04-FEB-87 | 2.4361 | 23.59 | 2.4866 | 27.03 | 1.7248 | 357.01 | 1.5551 | 359.45 | 2.1963 | 345.36 | 2.2138 | 346.48 |
| 06-MAY-87 | 2.3222 | 21.21 | 2.4454 | 25.75 | 1.7375 | 356.95 | 1.5900 | 359.55 | 2.1543 | 346.24 | 2.1458 | 346.04 |

TABLE C-2. - Tilt magnitudes and directions for foundation B, degrees

| | Tiltplate B1 | | Tiltplate B2 | | Tiltplate B3 | | Tiltplate B5 | | Tiltplate B6 | | Tiltplate B7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Tilt | Direc-tion | Tilt | Direc-tion | Tilt | Direc-tion | Tilt | Direc-tion | Tilt | Direc-tion | Tilt | Direc-tion |
| 19-DEC-84 | 0.0000 | 0.00 | 0.0000 | 0.00 | 0.0000 | 0.00 | 0.0000 | 0.00 | 0.0000 | 0.00 | 0.0000 | 0.00 |
| 09-JAN-85 | .1340 | 14.04 | .1875 | 90.76 | .2237 | 198.23 | .0459 | 209.36 | .0571 | 28.81 | .2376 | 358.79 |
| 14-JAN-85 | .0820 | 37.57 | .2366 | 74.05 | .2510 | 213.22 | .0706 | 157.07 | .0872 | 27.30 | .2875 | 359.50 |
| 15-JAN-85 | .2395 | 18.25 | .2761 | 77.98 | .3052 | 214.99 | .1705 | 355.79 | .1185 | 27.65 | .3688 | 8.19 |
| 16-JAN-85 | .2351 | 23.84 | .2976 | 79.35 | .3294 | 215.95 | .0230 | 40.60 | .1208 | 24.44 | .3780 | 7.22 |
| 17-JAN-85 | .2160 | 16.13 | .3062 | 76.30 | .3379 | 216.57 | .0301 | 311.63 | .1287 | 29.05 | .3773 | 9.15 |
| 18-JAN-85 | .3551 | 30.00 | .2809 | 69.15 | .3014 | 217.78 | .0928 | 274.64 | .1554 | 25.74 | .3983 | 3.60 |
| 19-JAN-85 | .3046 | 16.20 | .3473 | 69.35 | .3374 | 217.27 | .0581 | 25.46 | .1628 | 10.62 | .4220 | 13.71 |
| 22-JAN-85 | .5795 | 19.14 | .4990 | 52.33 | .4475 | 206.57 | .5010 | 191.31 | .3056 | 13.24 | .7683 | 11.64 |
| 23-JAN-85 | .6518 | 21.84 | .5315 | 48.81 | .5123 | 208.81 | .1266 | 350.91 | .3505 | 14.04 | .7850 | 11.20 |
| 24-JAN-85 | .6720 | 23.23 | .6060 | 50.86 | .5469 | 167.28 | .1555 | 355.39 | .3568 | 16.28 | .8459 | 10.21 |
| 28-JAN-85 | .7864 | 21.84 | .7216 | 52.18 | .5735 | 214.44 | .1759 | 354.29 | .4277 | 358.33 | .9815 | 7.76 |
| 29-JAN-85 | .7952 | 21.97 | .7196 | 50.78 | .5724 | 218.23 | .1862 | 345.22 | .4611 | 350.64 | 1.0007 | 7.32 |
| 30-JAN-85 | .7906 | 22.10 | .7605 | 53.02 | .5955 | 211.26 | .1895 | 351.66 | .4457 | 3.22 | 1.0066 | 6.56 |
| 31-JAN-85 | 1.0692 | 19.96 | .9046 | 49.71 | .6523 | 275.71 | .2866 | 6.01 | .5788 | 8.45 | 1.1307 | 9.55 |
| 01-FEB-85 | 1.6443 | 21.96 | 1.6404 | 31.41 | 1.5211 | 9.17 | 1.1669 | 18.36 | 1.3843 | 13.68 | 1.8072 | 15.07 |
| 02-FEB-85 | 1.8089 | 18.79 | 1.9010 | 25.55 | 1.8501 | 5.40 | 1.4822 | 11.48 | 1.6822 | 11.66 | 2.0229 | 12.49 |
| 04-FEB-85 | 1.8963 | 17.10 | 2.0599 | 29.52 | 1.9469 | 6.96 | 1.5783 | 11.79 | 1.7745 | 7.94 | 2.1264 | 10.98 |
| 05-FEB-85 | 1.9212 | 17.73 | 2.0681 | 28.21 | 1.9688 | 5.67 | 1.5983 | 11.27 | 1.8108 | 10.58 | 2.1609 | 10.46 |
| 06-FEB-85 | 1.9600 | 16.68 | 2.0822 | 27.76 | 1.9916 | 4.62 | 1.6141 | 10.89 | 1.8259 | 10.97 | 2.1741 | 10.53 |
| 07-FEB-85 | 1.9932 | 16.62 | 2.1203 | 28.83 | 1.9690 | 4.60 | 1.5979 | 10.73 | 1.8286 | 8.17 | 2.2121 | 10.15 |
| 08-FEB-85 | 2.0312 | 16.00 | 2.1755 | 30.99 | 1.9350 | 5.15 | 1.5693 | 10.09 | 1.8202 | 4.33 | 2.2482 | 9.47 |
| 13-FEB-85 | 2.1071 | 16.05 | 2.0241 | 31.00 | 2.0097 | 4.88 | 1.6054 | 9.14 | 1.8481 | 6.13 | 2.2721 | 8.86 |
| 15-FEB-85 | 2.1257 | 15.83 | 2.1896 | 30.84 | 1.9848 | 6.98 | 1.6121 | 11.00 | 1.8429 | 5.29 | 2.2971 | 8.39 |
| 19-FEB-85 | 2.0371 | 16.32 | 2.1312 | 27.38 | 2.0581 | 5.21 | 1.6398 | 7.71 | 1.8639 | 9.18 | 2.1949 | 8.65 |
| 22-FEB-85 | 2.0848 | 15.65 | 2.1301 | 27.47 | 2.1276 | 4.87 | 1.7098 | 8.15 | 1.8528 | 7.36 | 2.2060 | 6.90 |
| 26-FEB-85 | 2.0398 | 13.61 | 2.0980 | 25.25 | 2.2453 | 1.51 | 1.7613 | 7.18 | 1.8654 | 7.93 | 2.2416 | 9.24 |
| 05-MAR-85 | 2.0909 | 12.36 | 2.1405 | 27.85 | 2.1673 | 359.44 | 1.9833 | 10.90 | 1.8760 | 8.58 | 2.2860 | 9.44 |
| 08-MAR-85 | 2.0609 | 12.75 | 2.1012 | 25.44 | 2.1622 | .37 | 1.7960 | 11.89 | 1.8781 | 8.50 | 2.3218 | 9.11 |
| 21-MAR-85 | 2.0516 | 12.24 | 2.1066 | 25.74 | 2.1097 | 359.61 | 1.8041 | 12.32 | 1.8906 | 9.44 | 2.4176 | 9.04 |
| 13-APR-85 | 2.0809 | 12.70 | 2.1480 | 27.37 | 2.1674 | 358.98 | 1.8488 | 12.50 | 1.8965 | 8.64 | 2.5468 | 8.69 |
| 17-MAY-85 | 2.0916 | 11.44 | 2.2032 | 29.50 | 2.0255 | 358.05 | 1.6624 | 16.06 | 1.9138 | 8.56 | 2.6361 | 9.50 |
| 31-MAY-85 | 2.1083 | 11.63 | 2.2087 | 28.83 | 2.0981 | 357.95 | 1.8835 | 12.34 | 1.9241 | 8.59 | 2.6704 | 8.29 |
| 03-JUL-85 | 2.2596 | 7.05 | 2.2657 | 21.01 | 2.3051 | 354.44 | 2.1338 | 7.61 | 2.1232 | 4.19 | 2.8407 | 3.63 |
| 25-JUL-85 | 2.2670 | 4.49 | 2.2789 | 19.55 | 2.2827 | 350.96 | 2.1807 | 6.32 | 2.1619 | 3.65 | 2.8847 | 2.24 |
| 23-AUG-85 | 2.2863 | 3.32 | 2.2782 | 20.42 | 2.2379 | 350.80 | 2.1873 | 3.80 | 2.1877 | .79 | 2.9200 | .05 |
| 24-SEP-85 | 2.2818 | 2.26 | 2.2501 | 20.69 | 2.2175 | 351.41 | 2.1181 | 5.01 | 2.1871 | 2.49 | 2.9077 | .69 |
| 17-NOV-85 | 2.2608 | 3.11 | 2.2891 | 20.79 | 2.1618 | 2.99 | 2.1580 | 1.19 | 2.1825 | .13 | 2.8826 | 359.55 |
| 18-JAN-86 | 2.3174 | 2.60 | 2.2863 | 19.88 | 2.1263 | 349.72 | 2.2065 | 2.14 | 2.1902 | .78 | 2.9153 | 359.21 |
| 01-APR-86 | 2.3301 | 2.71 | 2.2895 | 18.40 | 2.1764 | 347.51 | 2.2110 | 3.24 | 2.2000 | .26 | 2.9251 | 359.61 |
| 23-JUL-86 | 2.2595 | 2.41 | 2.2944 | 17.76 | 2.2041 | 355.73 | 2.2420 | 2.43 | 2.1978 | .98 | 2.8625 | 359.85 |
| 28-OCT-86 | 2.3208 | 1.54 | 2.2869 | 19.74 | 2.1916 | 358.76 | 1.9109 | 1.72 | 2.1975 | .13 | 2.9003 | 359.11 |
| 04-FEB-87 | 2.3460 | 1.65 | 2.2885 | 20.93 | 2.0291 | 348.19 | 2.1309 | 1.68 | 2.1902 | 359.15 | 2.9205 | 358.97 |
| 06-MAY-87 | 2.2963 | 1.93 | 2.3019 | 20.40 | 1.9990 | 357.62 | 2.1454 | 1.07 | 2.1550 | .13 | 2.9181 | 358.82 |

• U.S. GOVERNMENT PRINTING OFFICE: 1988-0-547-391

INT.-BU.OF MINES,PGH.,PA. 28767

U.S. Department of the Interior
Bureau of Mines--Prod. and Distr.
Cochrans Mill Road
P.O. Box 18070
Pittsburgh, PA 15236

AN EQUAL OPPORTUNITY EMPLOYER

**OFFICIAL BUSINESS**
**PENALTY FOR PRIVATE USE--$300**

☐ We do not wish to receive this material. Please remove us from your mailing list.

☐ Our address has changed. Please correct as indicated.